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ABBREVIATIONS AND SYMBOLS

Å.	Ångstrom unit(s) = 1×10^{-10} m.
A.C.	air-cooled ; alternating current
A.H.	air-hardened
amp.	ampère(s)
amp.hr.	ampère-hour(s)
approx.	approximately
at.-%	atomic per cent
at.wt.	atomic weight
atm.	atmosphere(s) (pressure)
A.W.G.	American wire-gauge
° Bé.	Baumé (degree)
b.h.p.	brake horse-power
B. & S.	Brown and Sharpe (gauge)
B.o.T.	Board of Trade
b.p.	boiling point
B.T.U.	Board of Trade unit(s)
B.Th.U.	British thermal unit(s)
B.W.G.	Birmingham wire-gauge
° C.	centigrade (degree)
cal.	calorie(s)
c.c.	cubic centimetre(s)
c.d.	current density
c.g.s.	centimetre-gramme-second unit(s)
cm.	centimetre(s)
coeff.	coefficient(s)
conc.	concentrated
const.	constant(s)
cu.	cubic
cwt.	hundredweight(s)
D.C.	direct current
dia.	diameter
dil.	dilute
dm.	decimetre(s)
e.m.f.	electromotive force
e.v.	electron volt(s)
° F.	Fahrenheit (degree)
ft.	foot, feet
ft.lb.	foot-pound(s)
g.	gramme(s)
gal.	gallon(s)
H.F.	high-frequency
h.p.	horse-power
h.p.hr.	horse-power-hour(s)
hr.	hour(s)
in.	inch(es)
in.lb.	inch-pound(s)
I.S.W.G.	Imperial standard wire-gauge
° K.	absolute temperature (Kelvin scale)
kg.	kilogramme(s)
kg.cal.	kilogramme-calorie(s)
kg.m.	kilogramme-metre(s)
km.	kilometre(s)
kV.	kilovolt(s)
kVA.	kilovolt-ampère(s)
kW.	kilowatt(s)
kWh.	kilowatt-hour(s)
kX.	crystal Ångstrom(s) = 1000 Siegbahn X-units
lb.	pound(s)
L.F.	low-frequency
M	molar (solution)
m.	metre(s)
m.amp.	milliampère(s)
max.	maximum
mg.	milligramme(s)
min.	minimum ; minute(s)
ml.	millilitre(s)
mm.	millimetre(s)
m.m.f.	magnetomotive force
m.p.	melting point
mV.	millivolt(s)
mμ	millimicron = 1×10^{-9} m. = 10 Å.
N	normal (solution)
N.T.P.	normal temperature and pressure
O.H.	open-hearth ; oil-hardened
O.Q.	oil-quenched
oz.	ounce(s)
p.d.	potential difference
*p*H	hydrogen-ion concentration
p.p.m.	parts per million
r.p.m.	revolutions per minute
sec.	second(s)
sp.gr.	specific gravity
sq.	square
S.W.G.	standard wire-gauge
T.	tempered
temp.	temperature
V.	volt(s)
VA.	volt-ampère(s)
W.	watt(s)
Wh.	watt-hour(s)
W.G.	water-gauge
W.Q.	water-quenched
wt.	weight
wt.-%	weight per cent
yd.	yard(s)
μ	micron(s) = 1×10^{-6} m.
μg	microgramme(s) = 1×10^{-6} g.
μμ	1 millionth micron = 1×10^{-12} m. = 0·01 Å.
Ω	ohm(s)
°	degree (arc or temperature)
′	minute of arc ; foot (feet)
″	second of arc ; inch(es)
$<$	less than
$>$	greater than
$\not<$	not less than
$\not>$	not greater than
$\leqslant$	equal to or less than
$\geqslant$	equal to or greater than
$\neq$	not equal to
$\equiv$	identically equal to
$\simeq$	approximately equal to
$\propto$	proportional to

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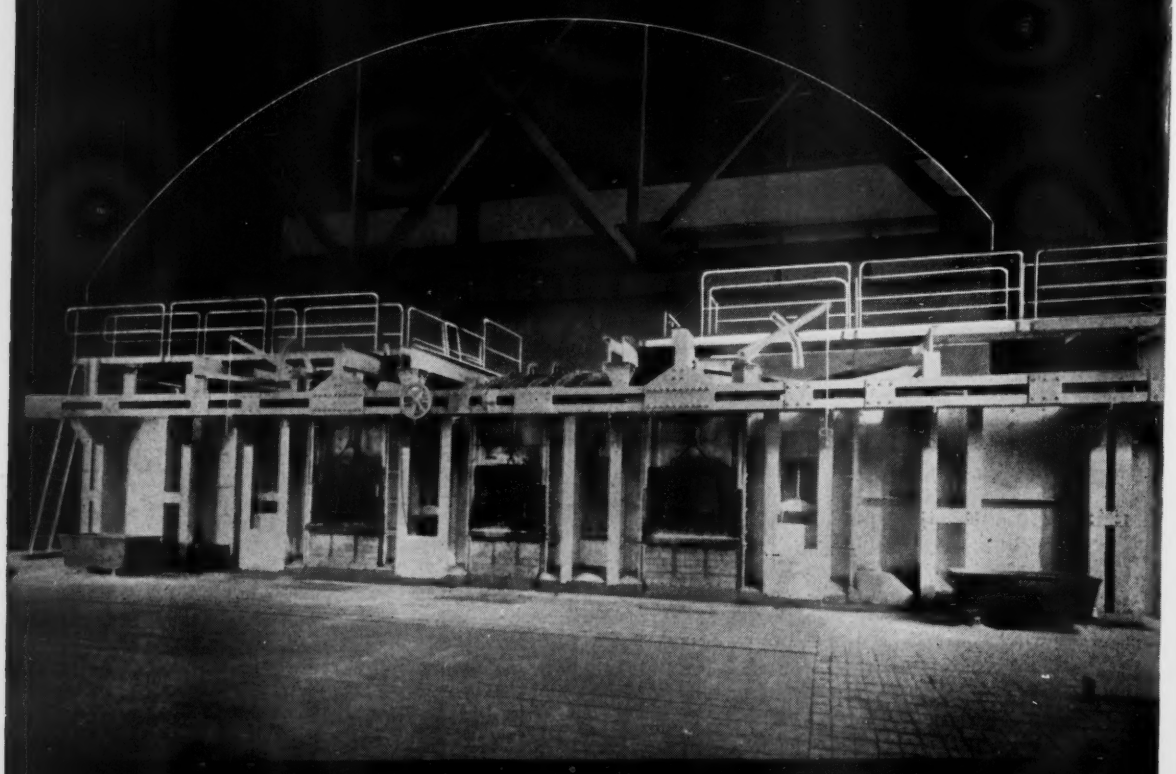
WELLMAN



Furnaces

Recently installed in a leading British Roll Foundry, this Wellman 40-Ton Open Hearth Acid Steel Melting Furnace was designed specifically to allow complete 15-Ton scrapped rolls to be charged through the furnace roof as an alternative to the normal method of charging.

We have a wide experience in this particular branch of metallurgy, and our overseas connections make it possible for us to incorporate the most modern developments in American and Continental steel making practice.

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News and Abstracts

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Photo by courtesy of South Durham Steel & Iron Co. Ltd.

A HOT PLATE LEVELLER by Davy-United

TODAY, APPROXIMATELY HALF OF THE TOTAL manufacturing capacity in the United Kingdom for forging presses, rolling mills, mill auxiliary machinery and other similar plant is contained within the works of the Davy-United Group.

Typical of the wide range of Davy-United products in this field is this Hot Plate Leveller. This machine is designed for the levelling of plates coming direct from the rolling mill and is installed between the Mill and Cooling Banks.

The machine is of the backed-up roll type and incorporates 9 work rolls (4 top and 5 bottom) with 2 top conveyor rolls. The work rolls are 11 in. dia. x 12 ft. 7 in. long.

The width between the guide rolls of 12 ft. enables the machine to handle plates of $\frac{1}{4}$ in. to 2 in. thick x 11 ft. 10 in. wide, while the main driving motor of 150 h.p. gives a plate rolling speed of 42/84 ft. per minute. It was in the Glasgow Works of the Group that this Leveller was designed and built.

DAVY AND UNITED ENGINEERING COMPANY LIMITED, SHEFFIELD

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DR. ING. J. GÖRRISSEN

JOHAN GÖRRISSEN was born in Oslo in 1907. On leaving school he continued his studies, first at the Oslo School of Commerce, and later at the Technical University of Norway, Trondheim. In 1930, he graduated as a Chemical engineer, and immediately joined Bergverkselskapet Nord-Norge, being appointed plant superintendent of their ore concentration plant at Mo i Rana. After two years, however, he went to the Technische Hochschule, Aachen, where he was engaged in research work on ferrous metallurgy ; in 1934, he submitted a thesis on desulphurization and was awarded the degree of Dr. Ing.

In 1934 Dr. Görrissen returned to Norway to join Christiania Spigerverk in Oslo, and since 1937 he has held the position of Director of Research. Among the many problems investigated under his supervision those of the smelting of titaniferous ores and brittleness in mild steels were prominent ; a Paper on the latter subject is published in this issue for presentation at the Institute's Special Summer Meeting in Norway. He has now been appointed General Manager of A/S Fiskaa Verk, Kristiansand S., and will take up his new duties next June.

Dr. Görrissen's activities during the war resulted in his arrest by the Gestapo in October, 1942, and he was held in Norwegian and in German concentration camps until the cessation of hostilities.

The work of the technical societies of Oslo has always been of great interest to Dr. Görrissen, and he has played an active part in his capacity as Vice-Chairman of the Society of Civil Engineers, Oslo Chapter, and today as President of Norsk Metallurgisk Selskap, the Norwegian Metallurgical Society.

GUNNAR SCHJELDERUP

GUNNAR SCHJELDERUP was born in Oslo in 1895. He left school in 1913 and finished his education as chemical and metallurgical engineer at the Technische Hochschule, Dresden, in 1917.

After three years as metallurgical engineer in the Norwegian, and later in the Canadian nickel industry, he studied open-hearth and electric steel-making in the U.S.A., and in Germany. In 1922 he became steelworks engineer at Christiania Spigerverk Iron and Steel Works, and in 1926 was appointed General Manager. He has been a member of the Board of that Company since 1938, and Chairman since 1947.

Owing to his intimate knowledge of the iron and steel industry, Mr. Schjelderup has been a member of a number of official committees dealing with the iron and steel industry in Norway ; one of the results of this work was the planning of the new A/S Norsk Jernverk, which is at present under construction. For his services, Mr. Schjelderup has been awarded the Order of Knighthood of St. Olav.

Mr. Schjelderup has taken an active and leading part in the development of other Norwegian industries. He founded and, during the first important years, acted as Chairman of the Norwegian Industries Development Association, which covers a great part of Norwegian industry. He is on the Central Committee of the Norwegian Employers' Association (Norsk Arbeidsgiverforening), and of its branch organization for the mechanical engineering industry (Mekaniske Verksteders Landsforening). He is also a member of the Boards of other Norwegian associations and industries.

During the last war, Mr. Schjelderup played an active part in opposing German activity in Norway, and was imprisoned, with his whole family, in October, 1944. He received General Eisenhower's award for brave conduct.

IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

Agglomeration of Taconite Concentrate

By Worm Lund, A.M.I.E.

SYNOPSIS

A description is given of the filter briquetting process employed at the Sydvaranger Iron Ore Co. before the war, this process having superseded the earlier sintering plant. Early tests with a pelletizing process are described, and a pilot plant is now being erected.

A DESCRIPTION of the Sydvaranger Iron Ore Company's taconite plant at Kirkenes, Norway, has been published in a recent paper.* A short description of the agglomeration of the concentrate in this plant is now given.

The pre-war yearly production of the company, was 2,000,000 metric tons of magnetic-taconite iron ore, assaying 30% magnetic iron. To produce 1 ton of concentrate, 2·3 tons of crude ore were required. Production of concentrate was 875,000 tons/yr., of which 440,000 tons were agglomerated as briquettes, and the remainder, which contained 5–7% of water, exported. To achieve a concentrate containing 66% total iron, the concentrate had to be ground to 5% + 150 mesh, and 65% + 325 mesh (Tyler). The concentrate consisted of 91·5% magnetite, 6·0% quartz, and 2·5% hornblende and other minerals. The assays showed, besides iron :

SiO_2, %	7·00	NaCl, %	0·30
Al_2O_3, %	0·60	TiO_2, %	0·01
CaO, %	0·40	P, %	0·01
Mn_2O_4, %	0·20	S, %	0·01

The magnetite was glittering and had sharp edges, while the quartz was sharp and transparent. The hornblende occurred in the shape of needles and flakes, and the minerals were found to be of importance to the agglomeration.

THE GRÖNDAL PRESS BRIQUETTING PLANT

As early as 1911, when the plant was first operated, difficulties were encountered with the agglomeration of a concentrate so finely ground. Having a press briquetting plant erected according to the Gröndal system, it was possible to overcome these difficulties.

The plant in question had a total of 12 tunnel kilns, each 40 m. long. The concentrate coming from the magnetic separators was dewatered in settling ponds, where the water content dropped to 20%, and after two days it was being transported by cranes to the concentrate storage, where it was air dried to 12–14% of water. Using the press briquetting process, it soon appeared necessary to keep the moisture content between narrow limits, in order to obtain strong briquettes. The concentrate had to be dried, therefore, in rotary-drum driers before being pressed to briquettes, and it was difficult to keep an even moisture content. The sharp-edged concentrate resulted in heavy wear on the press pistons and forms.

Working under a pressure of 300 kg./sq. cm., the press made briquettes weighing 5 kg. The briquettes were placed manually, in two layers, on the briquette cars which each carried two tons. This was heavy work, and could hardly be performed today.

The tunnel kilns were heated by producer gas, and when the concentrate had the correct moisture content, and the kilns were carefully looked after, briquettes of good quality were produced.

SINTERING

Because of the heavy manual work, the wear on the presses, and the difficulties of keeping an even moisture content in the concentrate, a Greenawalt sintering plant was erected in 1921. After three years' operation this plant had to be closed. The sintering, which had shown very good results on other iron concentrates, could not be applied economically to the finely ground concentrate.

More recently, the company has performed sintering tests to discover if the sintering process could be improved. These tests have shown that, although it is possible to obtain better results than with the old Greenawalt plant (which had a capacity of 4 tons/sq. m./day), with a suction of 760 mm. of water, the results are still not good enough to justify the erection of a new sintering plant. Today, we can rely upon a capacity of 6·5 tons/sq. m./day, when using a suction of 1700 mm. of water. The considerable vacuum causes a high power consumption ; about 80 kWh. per ton of sinter. The sintering capacity is almost in proportion to the vacuum, but the degree of oxidation is only 96%, which is rather low.

In order to obtain a higher degree of oxidation, the coke consumption must not exceed 4%. If the coke consumption is increased from 4 to 5%, the sinter

* W. Lund, *Mining World*, 1948, Oct., pp. 38–41.

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Mr. Lund is Mining Engineer to the Sydvaranger Iron Ore Company, Kirkenes, Norway.

becomes hard burned with coarse canals, and partly fused, but its capacity is increased by 25%. The sinter obtains a pore volume of 57%, and will require a loading volume, in ships, of 0·8 cu. m./ton. To obtain good sinter, the coke must be finely ground, preferably below 1 mm. Furthermore, the coke must be well mixed with the concentrate. Such mixing cannot be carried out by blending coke and moist concentrate after the usual practice in pug mills. At present, we do not know a better way than to dry coke and concentrate before mixing. This causes considerable extra cost and is not a satisfactory process, because the concentrate requires moistening again to 7% of water before sintering.

It is possible, however, to produce a good sinter from the Sydvaranger concentrate, in a modern Greenawalt, A.I.B., or Dwight Lloyd sinter plant. The low capacity of the plant, and the difficulties in connection with the crushing of the coke, as well as the mixing by a dry process, cause high production and amortization costs. The sinter produced will be of good quality, but not so easily reducible as the briquettes, nor so well suited for export, as it will not resist the crushing effect of several handlings by bucket cranes. If the sinter is burned harder, it is still not easily reducible, and will consume more coke and require a longer reduction time in the blast-furnace.

Before the war, about half of the concentrate was exported to Germany, where it was used for mixing with coarser ores. To avoid a substantial reduction of the sintering plant's capacity, the content of the Sydvaranger concentrate had to be kept below 25%. Because of its high iron content and lack of undesirable elements, the concentrate was a suitable product to mix with German ores of poorer quality.

To obtain a good sinter, it must be properly cooled on the grates. Under no circumstances must the red-hot sinter be sprinkled with water, as this seriously reduces its strength. A good sinter has the look of a good metallurgical coke. It has finely divided pores, and is hard, without being fused. A modern sinter plant can be made almost free from dust and, given good control, it could be worked without serious difficulties.

The drawbacks of the sintering process, previously mentioned, are the reasons why, as far as Sydvaranger is concerned, a new sintering plant will not be erected at Kirkenes.

THE FILTER BRIQUETTING PROCESS

When sintering was discontinued, in 1924, Mr. Leif B. Gundersen, the sintering superintendent at that time, attempted to make a better briquetting process, and finally achieved the filter briquetting process, Norwegian Patent No. 47695.

The old Gröndal briquetting kilns were enlarged from 40 to 70 m., and the briquetting cars were enlarged to 2·6 × 2 m. Each kiln was equipped with a coal pulverizer, and automatic registration of temperatures and gases. Ten kilns could then be fired and controlled by two men. It was possible to use cheap coal, and cheaper heating was obtained by better insulation of the kilns. The capacity of each kiln was increased to an average of 44,000 tons of briquettes per year.

The most important improvement on this type of kiln is the filter briquetting, which makes it possible to filtrate the briquettes on the cars ; thereby, the heavy manual work of placing the briquettes on the cars is avoided. A filter frame of the same dimensions as the car is mounted in front of each kiln. The filter frame is divided by suction boxes, which fill in the space between the briquettes.

The concentrate, which was dewatered in the settling ponds and stored for about one month, was mixed with return dust and transported by cranes to the bins in front of the kilns. The concentrate was fed from the bins to the agitator above each filter. This agitator was fed periodically with a charge corresponding to the capacity of the filter frame. The concentrate was mixed with water to 75% solid, and kept in suspension by a slowly rotating propeller.

Having automatically placed the briquette car under the filter frame, the filter frame was lowered on to the car. The filter operator opened the valve to the agitator, and the pulp was fed through a rubber hose to the spaces between the rubber boxes. Afterwards, the operator smoothed the surface with a shovel.

During the first two minutes, the vacuum was maintained at 670 mm. of mercury, and the water content dropped rapidly to 14%. In the following 4 to 8 min., the vacuum was 500 mm. of mercury, and the water content dropped to 10%.

The filter frame was made of cast iron, wood, and stainless 200-mesh screen. After filtering 8000 tons, the screen had to be replaced, because it was partly clogged. Salt water is used for concentration at Sydvaranger, and the filter must therefore be made of a stainless material. It is remarkable that, although a 200-mesh screen was used, only 0·5% of concentrate went through it. The suction boxes in the filter were conical in shape and gave the briquettes dimensions of 98 mm. at the head, and 122 mm. at the root. The briquettes were 375 mm. high and 195 mm. long. The weight of a burned briquette was 20 kg., and the pore volume 30%. Its specific gravity was 2·8.

After the suction had been completed, the filter frame was raised and the green briquettes left on the car. The filter frame with the suction boxes was made so that the suction boxes on one side of the briquettes were lifted 2½ in. before those on the other side. Their conical shape, and this method of lifting the filter, prevented the briquettes from adhering to the filter. The briquetting car was then fed automatically into the kiln, and met the exhaust gases which had a temperature of 150–200° C.

The briquettes were dried in the first section of the kiln. It is important that such drying does not take place so fast that the briquettes explode as a result of the steam produced. If dried too fast the briquettes will crack like the leaves of a cabbage ; thereby the heat conduction will be reduced and the briquettes will lose some of their strength.

The burners in the heating zone are placed in the arch, which, in this part of the kiln, is lifted slightly. The flame enters almost horizontally, in such a way that it does not touch the briquettes, thus preventing them from fusing.

The combustion air is sucked through the kiln from

the discharging end and cools the briquettes. In this way the combustion air is heated to 800° C. When the cars leave the kiln the briquettes have a temperature of 200° C. The cars are emptied automatically by tilting them at 50° into a dust chamber. The briquettes fall off, and the cars are returned automatically to the feed end of the kilns. During this process the cars receive a layer of return dust $\frac{3}{4}$ in. thick.

The briquettes are screened over a grizzly with $\frac{1}{2}$ in. spalt, and those under size are usually 10–20% of the amount produced.

The roller bearings on the cars are greased with graphite. They carry a layer of refractory bricks, and on top of this a layer of iron briquettes. This top layer, and the layer of return dust, make it possible to pour the pulp directly on to the warm cars. If hot refractory bricks are used they will crack when pulp is poured on to them. In this way the maintenance of the cars was reduced. One operator could handle the filtering and feeding of two kilns.

The cars were fed to the kiln at even intervals, and the regulation of the kilns was carried out by the two operators in charge of the firing. With the aid of their controlling instruments, and by judging the finished briquettes, they regulated the operation of the kilns by the feeders to the pulverizers. The power consumption of the pulverizers was 30 kWh. per ton of coal pulverized to 90%—200 mesh. The filters consumed 3 kWh. per ton of briquettes, and the total power consumption for the whole plant, including the transport facilities, was 18 kWh. per ton of briquettes.

The exhaust gases left the kiln at 100–150° C., and the atmosphere in the kiln was oxidizing. The coal consumption, when using 6000 kg.cal. coal, was 8–9%. Operation costs, in 1939, were about 5*s*. per ton, half of which was for coal. The filter briquettes obtained were of a better quality than the press briquettes, and the difficulties in keeping a concentrate with the right moisture content were overcome. The moisture content was kept constant automatically at 10%.

The degree of oxidation of the briquettes was 98%. The sinter, as compared with the filter briquettes, contained 1% less iron, and the degree of oxidation was more than 2% lower. The volume weight was only 67% of the briquettes' volume weight. This is of great importance to the blast-furnace operation.

The speed of the gas through the kilns had to be kept within limits to prevent the dust stirring up, as stirred-up dust would react with the refractory bricks in the burning zone, and form a slag which would flow down the wall and form crusts that might block the cars.

When using modern kilns better heat economy can be obtained, and in such circumstances the coal consumption ought to be reduced to 5–6%. The operation of the kilns is easy and, if the whole plant is of modern design, it can be kept almost dust free.

As opposed to the sinter, the briquettes can stand handling by bucket cranes, without producing too much fines. They have been exported mostly to England, where they are quite popular.

As mentioned previously, the concentrate had to be stored one month before good briquettes could be made. Later tests have shown that the same results can be obtained by demagnetizing the concentrate before briquetting. The pulp from the magnetic separators could be demagnetized and pumped direct to the agitator. As a matter of interest, no binders were used during the briquetting process. Tests with lime and other reagents have been undertaken, without giving better results.

The filter-briquetting process helped the company to solve the difficult problem of agglomerating a very finely ground concentrate. It was the only process found suitable to produce good practical results.

During the German retreat from the northern part of Norway, the Sydvaranger plant was completely destroyed and will now have to be rebuilt.

PELLETIZING

As early as 1935, tests were carried out in Germany, using the pelletizing process on the concentrate. The pellets were rolled up in the same way as described in Swedish Patent No. 35124, of 1912, and the green pellets were sintered on a Dwight Lloyd machine. This form of sintering was not the right method, and the tests were discontinued. The tests had proved that the concentrate could easily be made into pellets by balling them up in a revolving drum.

When these pellets were heated to 1150° C., they obtained a specific gravity of 3·5, and were an ideal material for the blast-furnace. Pellets 10 mm. in dia., were calculated to withstand a pressure of 40 kg. Such pellets can withstand transportation and handling better than the filter briquettes, which are bigger and therefore more exposed to crushing during handling by bucket cranes.

The problem is to construct a kiln suitable for burning pellets. In such a kiln, it should be possible to reduce the coal consumption to 3%. At the same time, the capital costs for the pelletizing plant should be less than for the filter-briquetting plant. As in the case of filter briquetting, a finely ground concentrate is also imperative in pelletizing.

A pilot pelletizing plant is now being erected at Kirkenes, and the results produced will determine whether the company will erect a new briquetting or pelletizing plant.

Acknowledgments

The sintering tests were supervised by the briquetting superintendent, Mr. Arne Stavang, assisted by the Swedish experts Mr. O. Aspegreen (Greenawalt method) and Mr. A. Holmberg (A.I.B. method). The Swedish plants, Sandvikens Jernverk, Arboga, and Landsverk, have been very kind in tendering advice, and in allowing their sintering plants to be used for tests.

The staff of the Sydvaranger company wish to express their gratitude to Mr. F. H. Berens, President of the company since 1911, who has always appreciated the importance of the problem of agglomeration of the taconite concentrate, and has given his staff the facilities for attempting to solve the problem.

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Iron Ore Concentration at Sydvaranger, Norway

By J. Kraft Johanssen, A.I.M.E.

SYNOPSIS

The paper describes methods of dressing, crushing, and concentrating magnetite iron ore mined at Aktieselskabet Sydvaranger, in Norway, and gives details of the composition of the ore. The method of concentrating by magnetic separation is discussed, as well as the degree to which the concentrate is dewatered.

The old plant, which was destroyed during the war, is described, and a flowsheet illustrates the stages and treatment through which the ore passed. The proposals for the new plant are outlined, and the advantages that will accrue from it are reflected in the simplified flowsheet.

AKTIESELSKABET Sydvaranger (Sydvaranger Iron Ore Co.) owns large deposits of low-grade magnetite iron ore in the district of Sör-Varanger, on the south side of the firth of Varanger in the county of Finnmark, in Norway. The harbour of Kirkenes, where the company had fine-crushing, concentrating, and briquetting plants, and works of different kinds, is situated at about 30° E. and 70° N. So far most of the mining has been done in an open pit at Björnevann (Bear Lake), about 5 miles south of Kirkenes. The pit is connected with the fine-crushing plant at Kirkenes by a normal-gauge railway.

The company started production in 1910, and up to the second world war it had produced 11 million tons of iron concentrate, containing 66–67% Fe, 7% Si, 0·009% P, and 0·02% S. About 5,800,000 tons of the concentrate had been turned into briquettes, with about 65% Fe and 0·008% S. The production in the pre-war years was at a rate of 800,000 tons of concentrate per year, which called for about 1,850,000 tons of ore as mined. About half of the concentrate was briquetted. The rest of the concentrate was shipped as such, with 5–7% moisture. The concentrate was exported to the Continent, and the briquettes mostly to England.

The company's plants at the open pit and at Kirkenes were destroyed during the war operations in 1944, and are now under reconstruction.

This paper contains a description of the method of ore dressing, the crushing and concentrating in the old plants, and an outline of the new crushing and concentration project.

THE ORE

The ore is an extremely hard, laminated, magnetite iron ore, quite similar to the American magnetic taconites of the Lake districts. The minerals in the ore are principally magnetite, quartz, and hornblende. It also contains small quantities of hematite (martite), pyrite, and apatite, and an analysis of the ore shows :

Total Fe, %	37·68	MgO, %	1·12
Fe_2O_3, %	36·71	CaO, %	0·48
FeO, %	15·40	TiO_2, %	0·08
SiO_2, %	43·92	P_2O_5, %	0·07
Al_2O_3, %	0·83	S, %	0·04
MnO, %	0·58		

The iron content of this sample is rather high. Usually the ore contains 34–37% total iron, of which 30–32% is magnetite iron. The balance is mostly iron in hornblende and some of it in hematite.

Figure 1 shows a thin section of the laminated ore. The darker lamellae consist primarily of magnetite and hornblende, the lighter lamellae of magnetite and quartz. It will be observed that there is a higher degree of complexity between magnetite and quartz than between magnetite and hornblende. The abundance

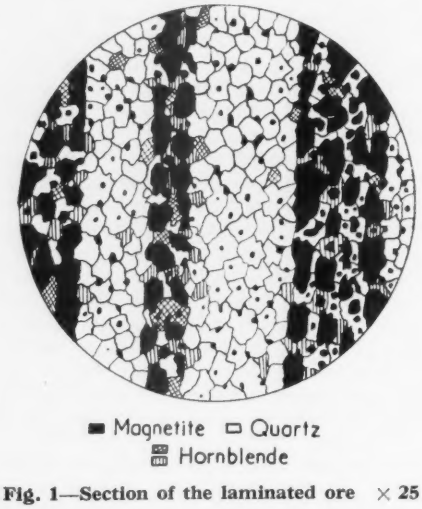

Fig. 1—Section of the laminated ore × 25

of very small magnetite grains scattered in quartz particles presents a difficult separation problem.

A sample of ore with a comparatively large amount of quartz will, at the same grind, yield a lower grade concentrate than a sample with less quartz and more hornblende, *i.e.*, the larger the difference between total iron and magnetite iron in the ore, the easier the ore is to concentrate. This difference in the mill heads was a good indication of the results which could be expected in the concentrator on a certain

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Mr. Johanssen is Technical Director at Aktieselskabet, Sydvaranger, Kirkenes, Norway.

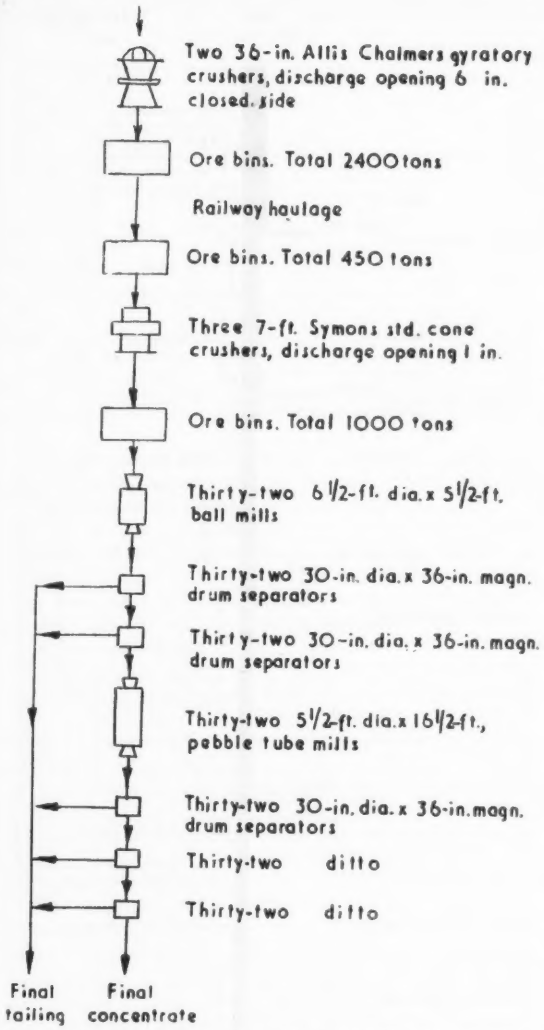
Two 36-in. Allis Chalmers gyratory crushers, discharge opening 6 in. closed side
Ore bins. Total 2400 tons
Railway haulage
Ore bins. Total 450 tons
Three 7-ft. Symons std. cone crushers, discharge opening 1 in.
Ore bins. Total 1000 tons
Thirty-two 6 1/2-ft. dia. x 5 1/2-ft. ball mills
Thirty-two 30-in. dia. x 36-in. magn. drum separators
Thirty-two 30-in. dia. x 36-in. magn. drum separators
Thirty-two 5 1/2-ft. dia. x 16 1/2-ft., pebble tube mills
Thirty-two 30-in. dia. x 36-in. magn. drum separators
Thirty-two ditto
Thirty-two ditto
Final tailing
Final concentrate

Fig. 2—Flowsheet for the old crushing and concentrating plants

lot of ore. Unfortunately the small ore bins and the equipment in the old mill did not permit this knowledge to be utilized.

To obtain a high-grade concentrate very fine grinding is necessary. Magnetic separation, applied to a magnetite ore, is probably the most efficient of the existing concentrating methods. One has, however, to bear in mind that, at least in wet magnetic separation, the middlings can be controlled only to a very small degree. The control has to be carried out in the grinding systems. The ore breaks down quite readily in ball mills to what may be called the primary particle size, but it is very hard to crush in the fine crushers, harder to crush in the primary breakers, and even harder to drill. The drilling is, by the way, the most difficult problem in exploiting an ore of this character. A simplified flowsheet of the crushing, grinding, and magnetic separation is shown in Fig. 2.

After crushing in two stages to about 1 in., the ore was ground in ball mills in open circuit to 5% + 20 mesh (Tyler), and separated in magnetic separators. The primary concentrate was reground in pebble mills in open circuit to about 5% + 150 mesh, and reseparated. The recovery of the magnetite was 97–98%.

Coarse Crushing

The ore in the pit was loaded by 2·75-cu. yd. steam shovels into 10-ton railway wagons, hauled to the coarse-crushing plant close to the mine, and dumped by overhead travelling cranes into the Allis Chalmers 36-in. all-steel long-shaft suspended-spindle primary gyratory crushers, each belt-driven from 250-h.p. motors. Average tonnage on one shift of 8 hr. was 1500 tons per crusher, with an idling time of 2–3 hr. The crushers were set to 6–8 in. on the closed side. The one-piece mantle material which gave the best results was a nickel–manganese steel of the following composition : 2·6% Ni, 12·3% Mn, 0·15% Cr, 1·10% C, 0·7% Si, and 0·04% P. The liners were made from the usual manganese steel. The consumption of crusher liners, mill liners, and grinding media is given in Table I. The crushed ore was conveyed to bins, loaded into 40-ton bottom-dump railway wagons, and hauled 5 miles by electric locomotives to the fine-crushing plant at Kirkenes.

Table I

CONSUMPTION OF LINERS AND GRINDING MEDIA, LB./METRIC TON

	Ni-Mn Steel	Mn Steel	Rolled Steel	Forged Steel	Quartzite	Danish Flint
Gyratory Crushers						
Mantle	0·025	...	...	...	...	...
Upper concaves	...	0·004	...	...	...	...
Intermediate concaves	...	0·008	...	...	...	...
Lower concaves	...	0·018	...	...	...	...
Symons Crushers						
Upper mantle	...	0·062	...	...	...	...
Lower mantle	...	0·005	...	...	...	...
Bowl liners	...	0·029	...	...	...	...
Ball Mills						
End liners	...	0·24	...	...	...	...
Shell liners	...	...	0·66	...	...	...
Balls	...	...	...	1·10	...	...
Tube Mills						
Liners	...	...	...	...	0·44	...
Pebbles	...	...	...	...	...	2·10

Fine-Crushing Plant

Three 7-ft. Symons standard medium-type crushers, each belt-driven from 300-h.p. motors, were fed by steel-apron feeders from the ore bins. At a 1-in. setting the capacity of each crusher was about 200 tons/hr. The ore contains comparatively little fines, and the lack of screens ahead of the crushers was not much of a drawback, unless the ore was wet. A short time before the war a 5½-ft. Symons short-head crusher was installed for testing purposes. This was operated partly in closed circuit with screens, and partly in open circuit ; the capacities obtained were :

Closed circuit : ⅜ in. sq. opening screen, 120 tons/hr.
½ in. sq. opening screen, 150 tons/hr.
Open circuit : Crusher set to $\frac{1}{16}$ in., 200 tons/hr.

The crusher was not operated for sufficient time to give any figure for the life of the manganese liners.

Figure 3 gives the size distribution in the product from the standard crushers and the short-head crusher. The standard-crusher product was the ordinary ball-mill feed.

Primary Grinding

The primary ball mills were of the overflow discharge type. The inside diameter of new shell liners was 5 ft. 9 in. The mills were driven by 100-h.p. motors at 30 r.p.m., *i.e.*, 94–98·5% of critical speed, depending on the inside diameter of worn liners. The capacity of each of the ball mills was 10·5–11·5 tons/hr. Shell liners were rolled square steel rods, with a railbase against the shell, and were spaced about 2 in. apart at the top. No bolts were used for the shell liners. End liners were made from manganese steel. The ball charge averaged 3·5–4 tons, and new forged-steel balls of 7 in. dia. (47·5 lb.) were fed to the ball mills at regular intervals. The size of the balls will probably cause some surprise. With a feed to the ball mill as shown in Fig. 3, the balls had to be of this size to deal with the hard and comparatively coarse feed. The diminution of the coarser part of the feed was more of a crushing operation than a grinding one.

Salt sea water was used as dressing water. It is not possible to state how much of the steel consumption in the ball mills should be ascribed to the corroding effect of the sea water. Figure 4 shows the solids/water distribution in the milling and concentrating process, and Fig. 5 gives the size distribution in the ordinary ball-mill discharge, and in the final iron concentrate.

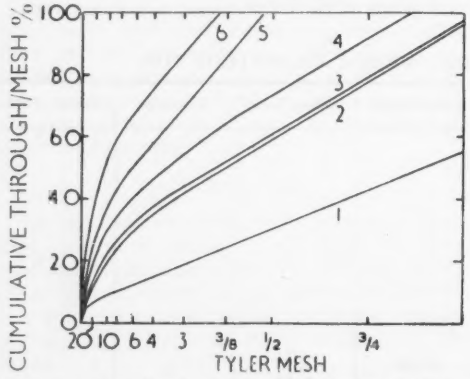

Fig. 3—Size distribution in Symons discharge: 1, Standard crusher set to 1 in. ball-mill feed; 2, 3, 4, Short-head crusher set to ⅝, $\frac{1}{16}$, and ¼ in. respectively; 5, 6, Short-head crusher set to ¼ in. for closed circuit with ½-in. and ⅜-in. screen respectively

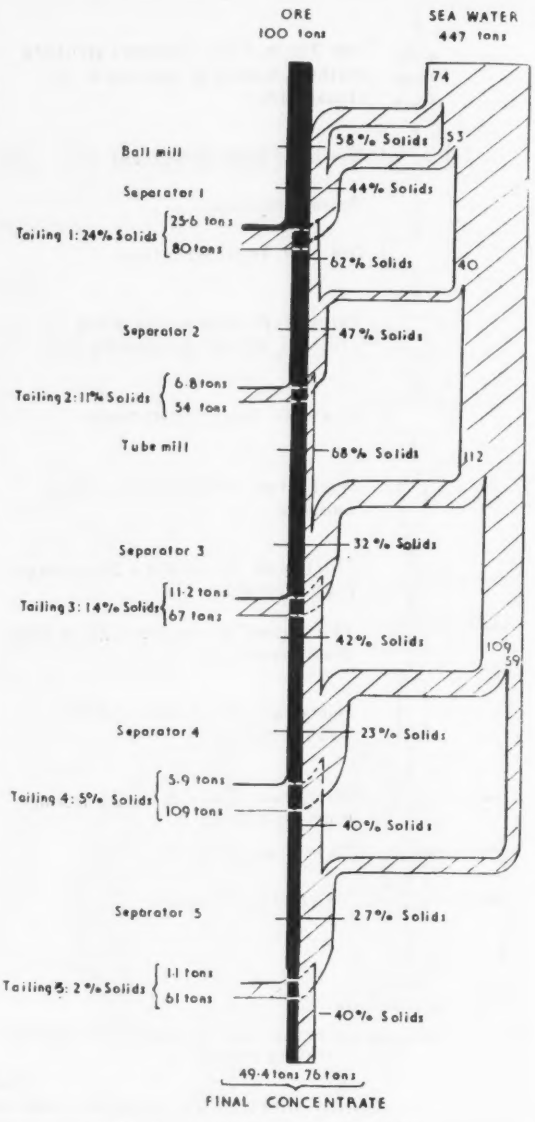

Fig. 4—Solids/water distribution

In connection with the test work with the short-head cone crusher, the influence of finer ball-mill feed on the capacity of one of the ball mills was investigated. As a matter of course the capacity increased considerably, but at the same time the ball mill discharged the material at a coarser grind than usual, and the feed rate had to be kept down to obtain a satisfactory magnetic separation. This shows that to utilize fully the increased capacity of a ball mill on

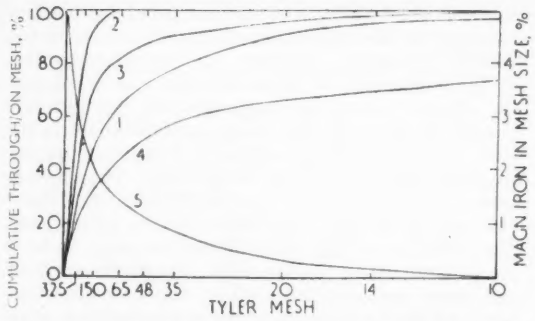

Fig. 5—Cumulative discharge through mesh: 1, Ball-mill discharge; 2, Final concentrate; 3, Composite (final) tailing. Cumulative discharge on mesh; 4, Percentage of magnetite in tailing; 5, Cumulative percentage of magnetite loss in tailing on mesh

a finer crushed feed, it is necessary to control the grinding by operating the ball mill in closed circuit with mechanical classifiers or screens.

A coarser ball-mill discharge decreased the grade of primary concentrate and increased the amount of primary concentrate. This would, of course, load up the secondary pebble mills, but even if the grind in the pebble mills was as fine as usual, the grade of the final concentrate decreased. The main reason for this is that when grinding coarser in the primary mill the middling particles in the primary concentrate constitute a larger part than when the ore is ground finer in the primary mills. After regrinding in the secondary tube mill to the ordinary mesh, the tube-mill discharge still contains more middling particles than usual, and a larger amount of middlings follows through the separators and contaminates the final concentrate. Only a small amount of the middling particles in the separator feed is rejected in the separator tailings.

Before 1930, when the Symons crushers were installed, sixteen 23 in. × 13 in. Hadfield jawbreakers were used as fine crushers, delivering a somewhat coarser feed to the ball mills. Then the grade of the final concentrate was 66·5–67·5% Fe; after 1930 the grade was 65·5–66·5% Fe, in spite of the same final grind. This confirms that the coarser the feed to the open-circuit ball mill, the finer the ball mill product, and illustrates the necessity of comparatively fine primary grinding when a high-grade final concentrate is wanted.

Secondary Grinding

The tube mills in the secondary grinding system were of the grate discharge type, with a diameter on new liners of 4 ft. 6 in. They were directly connected to 85-h.p. motors and were driven at 30 r.p.m., *i.e.*, 92–99% of critical speed. The capacity was 6–8 tons of primary concentrate per hour. The shell and feed-end liners were quartzite bricks; the grate and lifters were cast iron. Pebble charge was about 2·5 tons of Danish flint pebbles, with an initial size of 1½ in. at most.

The liner and pebble cost was comparatively low; the expensive item in the secondary grinding being the power consumption. The pulp in the tube mills had to be kept at about 70% solids to keep the speed of the pulp flow down, and the light grinding media had a very low grinding efficiency in this heavy pulp.

The feed to the tube mills depended on the feed to the ball mills and the quantity of primary concentrate produced. To control the secondary grinding, the feed to the ball mills had to be regulated, or, as was very often necessary, one ball mill had to be run for two tube mills in one or more systems to obtain an extremely fine discharge, thereby increasing the grade of the concentrate from these systems, and the grade of the combined concentrate from all systems.

Magnetic Separation

All five separators in each unit made final tailings. The concentrate from the first separator was cleaned once (primary concentrate) before regrinding, and thrice more after regrinding. No attempt was made to re-treat the tailings from the four cleaner separators, because of the small metal loss in these tailings. Total recovery of magnetite in the final concentrate was, as mentioned, 97–98%, and of the 2–3% lost, between 30 and 40% was magnetite in the cleaner tailings. The following may be regarded as typical assays of the tailings from the different separators:

Separator	Total Fe	Magnetite
1	7·3	1·5
2	7·6	1·5
3	6·8	0·9
4	7·7	1·8
5	8·4	2·0
Total	7·3	1·4

Each separator drum had two sets of electro-magnets with four poles each. Oxidized aluminium square wire, 2·2 mm. × 2·2 mm., was used in the coils, and the total ampere turns of one magnet were about 18,400 in continuous operation. The separators were of the Gröndal type, with brass heads. Most of the drums were of copper sheets. Copper is probably the most unfavourable material to use in separator drums, primarily because of the eddy currents which are induced and which act as electrical brakes on the drums. Research work at Kirkenes, just before operation ceased because of the second world war, showed that the primary demands of the drum material should be low electric conductivity, low magnetic permeability, and low coercivity. Stainless steel sheet with the correct chromium/nickel ratio was the best material tried out, because of the power necessary to revolve the drums and because of the strength of the magnetic field developed.

The composite final tailing was laundered to the firth at a pulp density of about 12% solids. The slope of the launder was 1–1½ in 100.

Dewatering

The final concentrate was dewatered to 15–20% of water in seven concrete vats, each with a capacity of 2000 tons of wet concentrate. The vats were emptied by overhead electric travelling bucket cranes, and the concentrate was stocked in magazines with a total capacity of about 100,000 tons. The magazines were serviced by similar cranes, and by a rather intricate routine of moving and piling the concentrate some further dewatering took place. A part of the concentrate was dried in rotary dryers to 5–7% of moisture. The very fine concentrate showed a strong tendency

to shift in the holds when shipped in bulk, and the Norwegian Shipping Board had set an upper limit of 7% and a lower limit of 4% of moisture in concentrate to be shipped.

Filtering tests on final concentrate were made at Kirkenes with a 9-sq. ft. inside drum filter. A filter cake with 9–10% of water and a filter capacity of 160–180 lb. of concentrate per square foot per hour can be expected when a feed with 50% solids is provided.

The following is a summary of the concentration results for the year 1940 :

	Total Fe	Magnetite
Heads	34·53	31·29
Concentrate	66·14	...
Final tailings	6·54	1·63
Recovery	89·95	97·25

Figure 5 gives the size distribution of a composite tailing with 1·6% magnetite iron ; it also gives the content of magnetite iron in the different mesh sizes, and the distribution of magnetite loss.

The power consumption in crushing, grinding, and concentration is shown in the following summary :

	Power Consumption kWh./ton of Ore
Coarse crushing	0·50
Hauling	0·10
Fine crushing	1·10
Conveying	0·20
Primary grinding	6·75
Secondary grinding	6·10
Magnetic separation	1·00
Water pumping	2·90
Light, etc.	0·20
Total	18·85

An assay of a final concentrate of 66·42% Fe is as follows :

Fe_3O_4, %	91·78	MgO, %	0·30
SiO_2, %	7·05	S, %	0·019
Al_2O_3, %	0·22	P, %	0·009
Mn_3O_4, %	0·12	NaCl, %	0·26
CaO, %	0·45		

THE CONCENTRATOR PLANT

It will have been gathered that the Sydvaranger flowsheet was a very simple one. This was, of course, an advantage, but the large number of comparatively small units in the concentrator plant demanded a large maintenance crew. The lack of large bin capacity was partly compensated for by the many units, but was nevertheless a nuisance.

The plant was thirty years old and, inasmuch as it was considered a pioneer work on this type of ore, it was also recognized that the economical and technical results could be improved with modern equipment.

A few years before the last war a thorough study was started to find out what actually took place in the concentration of the ore, and a programme for testing other possibilities, particularly of grinding methods and equipment, was laid out. The war and the destruction of the plants put an end to this. When it was realized that complete reconstruction of the plant was necessary, a thorough examination of the collected statistical material was made, and laboratory-scale test work has been carried out in the United States and in Norway.

The research work before the war was principally based on chemical assays, screen analyses, and microscopical analyses of the size fractions. Dings magnetic tube tester was used on finely pulverized materials for the estimation of magnetite iron in the different products. Further, an electric apparatus for the estimation of magnetite iron was developed. The sample containing magnetite was brought into a magnetic field and the change brought about in the field was measured by methods depending on the magnetic properties of the sample only. The readings were calibrated to give the content of magnetite iron.* This apparatus gave a method which, in a very short time, furnished figures of sufficient accuracy to be of the greatest value. This method, or a similar method, will most probably be used in the new plant for assaying the tailings from the separators—it saves time and chemicals. For two years about one hundred chemical assays were made daily at Kirkenes for the concentrator only.

Dings magnetic tube tester is also a splendid aid, but it cannot be utilized efficiently unless in combination with chemical assays of the products from the tube tester. It had its great value in estimating magnetite iron, and the calibration of the magnetic field apparatus, or, as it was popularly called, "the permeameter," would not have been possible without it.

The microscopical analyses were the most valuable tool in studying the factors which had any bearing on the results obtained. Daily microscopical analyses on primary ball-mill discharge, final concentrate, and tailings, were routine procedure for estimating the percentage of magnetite, middlings, and gangue particles in the different products. The products were screened on Tyler laboratory screens, and each screen size was studied separately under the microscope. The particles were divided into groups with particles made up of 100, 75, 75 to 25, 25 to 5, and less than 5% of magnetite and of 100% gangue ; all percentages were by volume.

Table II shows the results of microscopical analyses on a regular ball-mill discharge, final concentrate, and composite tailing. Table III gives the results on the final concentrate from a type of ore more difficult to treat. It will easily be seen that the lower grade concentrate contains more middling particles at a finer grind than the higher grade concentrate in Table II.

As previously mentioned Sydvaranger ore is quite similar to the American magnetic taconites. In view of the intense research work carried out in the United States on the beneficiation of these ores, it may be of interest to compare a concentrate made from an American magnetic taconite with the concentrates shown in Tables II and III. The concentrate in Table IV is made from an American taconite at about the same grind as the Sydvaranger concentrate in Table II. Both the Sydvaranger concentrates show more free magnetite in the coarse sizes, and more particles with less than 5% magnetite in all sizes, than the taconite concentrate. The concentrate in Table IV contains more middling particles with 5–75% magnetite. The interpretation is that the intergrowth between the magnetite and the gangue is, as a whole, finer in the American taconite in question than in the Sydvaranger

* Rasmus Wiig, Norwegian Patent No. 72004.

Table II

MICROSCOPICAL ANALYSES

Tyler Mesh	Weight, %	Volume of Magnetite, %					Gangue, 100%	Computed Magnetite, %	Total Fe Assayed
		100	75	75–25	25–5	< 5			
Ball-Mill Discharge									
20	6·6	...	8·3	13·6	45·8	22·9	9·4	19·16	24·49
35	12·0	0·8	10·9	10·9	47·1	20·2	10·1	20·87	26·96
65	13·3	10·4	9·9	5·2	31·6	29·6	13·2	25·41	28·89
150	17·6	26·3	3·4	3·4	6·9	32·0	28·0	32·31	34·70
200	12·5	31·0	3·0	2·0	4·6	33·0	26·4	35·74	41·80
325	8·6	37·8	1·4	2·1	1·4	16·8	40·5	40·55	44·35
–325	29·4	39·8	...	...	...	2·0	58·2	39·84	42·60
Average	100·0	24·93	4·27	3·92	14·79	19·86	32·41	32·49	34·0
Composite Tailing									
20	1·5	...	...	1·1	7·5	57·0	34·4	2·44	7·35
35	4·2	...	...	0·3	3·8	59·7	36·0	1·82	7·22
65	5·9	...	...	0·3	4·5	57·2	37·8	1·84	5·50
150	12·5	0·4	0·4	0·7	2·6	53·2	42·7	2·42	4·95
200	12·8	0·4	...	0·4	1·2	29·6	68·4	1·30	4·50
325	11·0	1·0	...	...	0·8	28·8	69·4	1·66	5·05
–325	52·1	1·1	...	...	...	5·0	93·9	1·20	6·00
Average	100·0	0·78	0·05	0·20	1·11	22·95	74·91	1·49	5·60
Final Concentrate									
150	4·2	38·4	3·5	4·2	10·5	43·4	...	44·54	50·72
200	13·7	64·8	5·6	1·2	1·9	25·9	0·6	71·01	62·19
325	15·0	78·9	0·5	1·4	1·9	15·9	1·4	80·54	66·83
–325	67·1	91·3	...	...	...	2·5	6·2	91·35	70·50
Average	100·0	83·59	0·99	0·55	0·99	9·43	4·45	85·04	66·47

Table III

MICROSCOPICAL ANALYSES OF FINAL CONCENTRATE

Tyler Mesh	Weight, %	Volume of Magnetite, %					Gangue, 100%	Computed Magnetite, %	Total Fe Assayed
		100	75	75–25	25–5	< 5			
150	2·9	31·5	5·6	6·7	7·3	48·3	0·6	41·45	40·61
200	10·9	50·0	5·8	2·3	6·2	35·7	...	57·55	58·07
325	14·5	69·3	3·0	3·0	2·4	22·3	...	73·86	63·97
–325	71·7	89·0	...	...	...	3·7	7·3	89·07	68·99
Average	100·0	80·22	1·25	0·90	1·23	11·16	5·24	82·10	64·74

Table IV

MICROSCOPICAL ANALYSES OF CONCENTRATE FROM AN AMERICAN TACONITE

Tyler Mesh	Weight, %	Volume of Magnetite, %					Gangue, 100%	Computed Magnetite, %	Total Fe Assayed
		100	75	75–25	25–5	< 5			
150	5·3	8·9	9·6	38·8	25·2	16·7	0·8	39·5	41·3
200	12·5	27·2	8·8	26·0	22·8	14·0	1·2	50·5	50·0
325	16·1	54·1	3·7	12·2	16·9	11·5	1·6	65·3	57·3
–325	66·1	85·0	0·5	1·5	6·0	5·0	3·0	86·8	67·2
Average	100·0	...	...	...	...	...	...	...	62·1

ore, and that there are less of the quartz-enclosed fine magnetite particles. The American taconite is not so highly metamorphosed as the Sydvaranger ore, and a somewhat finer grind would probably be necessary to obtain a 66% concentrate by magnetic separation.

THE PROPOSED NEW PLANT

The building structure for the new plant will be erected in one stage. Equipment will be installed for the production of 500,000 tons of concentrate by the end of 1951, which will be raised to 1 million tons by the end of 1952. Figure 6 gives a simplified flowsheet for the new crushing and concentrating plant. The main principle is the same as in the old mill, but crushing will be done in three stages. There will be no closed circuit in the crushing plant, primarily because of the steel scrap which will accumulate in a closed circuit, as it cannot be removed by magnets when crushing a highly magnetic ore.

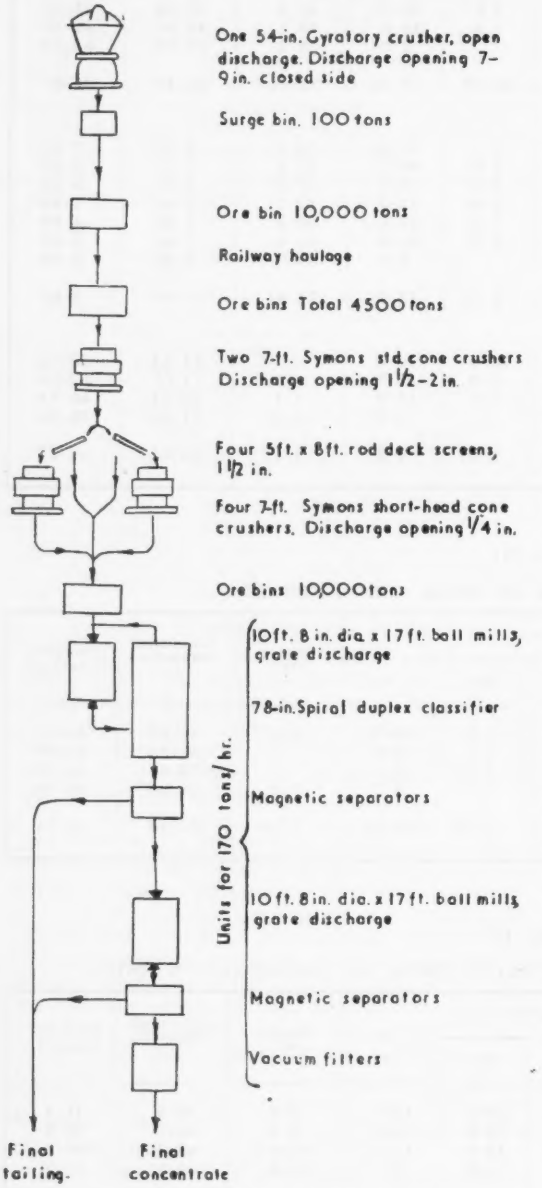
One 54-in. Gyratory crusher, open discharge. Discharge opening 7–9 in. closed side
Surge bin. 100 tons
Ore bin 10,000 tons
Railway haulage
Ore bins Total 4500 tons
Two 7-ft. Symons std. cone crushers Discharge opening 1½–2 in.
Four 5ft. x 8ft. rod deck screens, 1½ in.
Four 7-ft. Symons short-head cone crushers. Discharge opening ¼ in.
Ore bins 10,000 tons
10 ft. 8 in. dia. x 17 ft. ball mills, grate discharge
78-in. Spiral duplex classifier
Magnetic separators
10 ft. 8 in. dia. x 17 ft. ball mills, grate discharge
Magnetic separators
Vacuum filters
Units for 170 tons/hr.
Final tailing.
Final concentrate

Fig. 6—Flowsheet for the new crushing and concentrating plants

The 54-in. primary crusher will be the strongest gyratory crusher of this size hitherto built, and will weigh in the neighbourhood of 500 metric tons. It is cheaper to crush than to drill and blast the ore, and the choice of crusher size is governed by the largest blocks it will have to handle, rather than by the capacity of the crusher. The Symons crushers will all be of the super heavy-duty type ; the discharge from each standard crusher will gravitate over scalping screens direct to two short-head crushers.

As previously, grinding will be done in two stages, with ball mills at each stage. Primary grinding will be in closed circuit with mechanical classifiers, secondary grinding in open circuit. If closed circuit were used in the secondary circuit, the primary concentrate would have to be demagnetized.

Somewhat finer grinding is intended in the primary system than in the old concentration plant, firstly to increase the grade of the primary concentrate, and secondly to expel 40 to 45% of the feed to the primary separators as tailing—against 30 to 35% in the old mill. At a grind of about 35 mesh in the primary system, more of the magnetite will find its way into the fine sizes of the classifier overflow than in the old ball-mill product. A certain overgrinding of the magnetite particles will undoubtedly take place, and, for that reason, the use of classifiers also in the secondary grinding circuit has been considered, but there is still some doubt whether their use is necessary. There is a great difference between the behaviour of fine magnetite particles and, for instance, sulphide particles in a classifier. The magnetite is fast settling, and especially with the type of ore found at Sydvaranger, with very little primary slime and very fine middling particles, still more overgrinding can be expected in the secondary system when using classifiers, particularly if working with a very thin density in the overflow to keep the light middling particles in the sand. In any case, the light middling particles would tend to be carried through the system in the heavy pulp in the fast-moving circulating load, and eventually into the classifier overflow, without having been reduced sufficiently. An efficient demagnetization, particularly of the fine magnetite particles, seems to be a problem. The experience gained from the old plant and test work, indicates that open-circuit secondary grinding should be used for Sydvaranger ore when the demand is for a high-grade concentrate. Overgrinding of the fine magnetite will always take place, but there has to be a certain amount of fine material in the briquetting process and also if the concentrate is to be pelletized.

The number of grinding units in the new mill will be reduced to one-eighth of the number in the old mill for at least the same capacity. The estimate

for the total power consumption in the grinding systems is from 8 to 9 kWh./ton of ore.

The use of rod mills in open circuit in the primary grinding system has also been considered. Rod mills are very prominent in the United States as primary grinders, the advantages being that the feed to the rod mills can be kept coarser, thereby reducing the dust difficulties in fine crushing, and also that the rod mill produces a more uniform material. This is, of course, right, but grinding in a rod mill in the way described can hardly be carried any farther than to 10 or 14 mesh. A differential grind is required in the primary circuit. A coarser grind, as previously stated, and a uniform size distribution in the primary separator feed will reduce the grade in the final concentrate.

Even if a coarser primary grind would lower the operational cost for this stage it would increase the iron content in the tailing from the primary separators, and put a heavier load on the secondary mills. The lower recovery would demand a larger tonnage from the mine for the same production of iron units recovered in the final concentrate. This, in connection with the higher price per unit iron obtainable in a higher grade concentrate, makes the economical advantage of rod mills in this plant at least dubious.

The magnetic separators in the new concentrator will be principally of the same type as in the old plant. They will be improved mechanically and provided with stainless steel drums. If electromagnets are employed there will be at least four sets of magnets in each drum, compared with the two sets in the old type. Test work has shown that four poles on each magnet are hardly necessary, and reducing the number of poles will reduce the weight of the magnets sufficiently to increase still more the number of magnet sets in each drum. This will mean a reduction in prime cost and in space requirements, and will simplify the distribution of the feed to the first separators after the grinding systems. The distribution of the pulp to the magnetic separators is considered very important. An even feed along the whole length of the drum has a decided bearing on the capacity of the separator and on the recovery of the magnetite. This is perhaps evident, but it is a point which is very often neglected in practical operation. The final concentrate will be dewatered by filtering.

Tests are being carried out to investigate the feasibility of using modern permanent magnets in the separators. It is, however, too early to state definitely anything about the results of the tests.

In conclusion can be mentioned the possibilities of producing a very high-grade low-silica iron concentrate in smaller quantities for special purposes. Before the war there were occasional calls from a British customer for an iron concentrate with about 70% of iron. The only way of producing this at that time was to grind extremely fine in one of the secondary units. The following screen analysis was made of one of the lots of special high-grade concentrate which were shipped :

Mesh	Weight, %	Fe, %
+ 200	0·3	56·0
+ 325	3·1	66·0
− 325	96·6	70·9
Total	100·0	70·7

The concentrate contained 70·7% of iron and 1·6% of silica. The power consumption for the grinding only was 25 kWh./ton of ore. It may be of interest to mention that pellets made from this high-grade concentrate for test purposes were treated in a Söderfors reduction furnace with a resulting yield of sponge iron with 88·6% metallic iron and 93·6% total iron. The reduction ratio was 94·7%.

For the production of iron powder the content of silica has to be below 0·2% in the concentrate. This cannot be obtained with the Sydvaranger type of ore through fine grinding and magnetic separation only, but there is a possibility of removing the silica by flotation. Test work has indicated that by depressing the magnetite with sodium silicate in the ordinary concentrate, or possibly in a somewhat higher grade concentrate, and floating off the quartz, it may be possible to produce concentrate of the required specification.

A Brief History of Electric Pig-Iron Smelting in Norway

By Herman Christiansen, jun.

THE term ' Norway iron ' is still used in the United States of America to denote iron of very pure quality. This term dates back to the seventeenth or eighteenth century, when Norway exported, even to America, pig iron from its small charcoal blast-furnaces.

Faced with the growing competition of coke blast-furnaces, which were being erected in other countries, the small Norwegian installations were forced to close down by about 1850. Norway never built any coke blast-furnaces, and the once flourishing industry declined. However, the beginning of the present century saw a revival of the interest in iron smelting. Large iron deposits were disclosed and the development of the country's water-power resources gave

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Mr. Christiansen is a Metallurgist at Electrokemisk A/S, Oslo, Norway.

impulse to the study of methods for the electric smelting of iron.

THE FIRST ELECTRIC PIG-IRON FURNACE

In 1910 an electric pig-iron furnace, which produced high-silicon pig iron with coke as a reducing agent, was erected at Tinfos. Another furnace of the same type was put into operation in 1913 at Ulefoss, but further installations were never undertaken owing to various unsatisfactory features of design.

During these years, a tall-shaft, electric furnace, designed to be operated on charcoal—the ' Elektrometall ' furnace—had achieved considerable success in Sweden. Two such units were erected in 1911 at Tyssedal, in Hardanger. However, no charcoal was available in this locality, and the furnaces proved unsuitable for coke operation. Consequently, the Hardanger plant was closed down after a period of two years.

After a lull of ten years, the Norwegian Government (1922) financed a new series of tests on the electric smelting of iron ores with coke. These experiments were conducted by G. Tysland at A/S Fiskaa Verk. Christiania Spigerverk and Elektrokemisk A/S participated in the running of the tests, the latter company contributing with their experience in the design and operation of the Söderberg electrode system.

THE TYSLAND-HOLE FURNACE

The tests proved so successful that Christiania Spigerverk, in 1924, erected a 6000-kVA. furnace based on the experience obtained. This furnace was operated for three years until, in 1927, I. Hole was given the task of making certain modifications to the charging system to improve operating conditions: The result was very favourable, and from then onwards, the furnace was in more or less continuous operation for twenty years ; it was finally dismantled last year.

The furnace was a closed low-shaft furnace, equipped with three Söderberg electrodes in line, and a gas-cleaning plant. It proved to be a reliable production unit which could be operated on a cheap reduction material, *i.e.*, a mixture of coke and coke breeze.

A second installation of a 9000-kVA. unit followed at Bremanger in 1927, and since that time some twenty-two units have been built in other countries. The furnace is referred to as the Tysland-Hole furnace, or sometimes as the Spigerverk furnace, and is being designed and marketed by Elektrokemisk A/S. The later installations are principally the same as the modified original installation at Christiania Spigerverk, but several new improvements, such as the triangular arrangement of the electrodes, have been introduced. The furnace capacity has been increased to 13,200 kVA., corresponding to a daily output of approximately 90 tons.

PLANNING FOR THE FUTURE

During the period 1930–40, Norway's quality pig-iron production generally varied between 20,000 and 40,000 tons per year, of which a considerable part was exported. However, Norway imported many times that tonnage of iron and steel products, and there was a rising interest in the establishing of a new iron and steel works to cater for home consumption. The Government appointed a committee to draw up the lines for the future of the industry, and its recommendations were published in 1939.

Another committee was then appointed to prepare the necessary details for the presentation of the plans before Parliament. The war temporarily checked activities, but the plans had not been shelved, and a Government-sponsored company, A/S Norsk Jernverk, was formed. It was decided to build a new iron and steel works at Mo i Rana, in the north of Norway, near the minefields. In its initial stage, this plant is planned to produce some 200,000 tons per year, and will include three or four Tysland-Hole furnaces, electric steel furnaces, and rolling mills. A contract was signed with Elektrokemisk A/S for the design of electric pig-iron furnaces of 18,000–20,000 kW., *i.e.*, nearly double the capacity of the largest units hitherto in use. The design work is by now almost completed, and orders are being placed for equipment with Norwegian and foreign firms. The first unit is expected to commence operation by 1953.

At present a small community, Mo i Rana will, with the new activities, expand into a town of considerable size during the years to come, and much work is already being carried out in the construction of various facilities, as well as the building of houses. A new hydro-electric power plant of about 100,000 kW., which will deliver a current at 50 cycles, is under construction at Rösåga (25 miles from Mo i Rana). Originally, it was intended to supply the smelting furnaces with a current at 25 cycles, in order to halve the inductive losses which would otherwise make it difficult to design furnaces of the desired capacity. However, the cost of transmission lines for current of two different frequencies was considered excessive, and the cheaper solution of equipping the furnaces with condenser batteries for the correction of the power factor was adopted.

Those concerned with electric smelting practice will be awaiting with interest operating reports from this plant, partly because these reports will indicate whether or not electric pig-iron furnaces of still larger capacity can be constructed. The Mo works will operate exclusively on concentrated and agglomerated domestic ores, and electricity will take the place of more than one-half the amount of coke normally consumed in blast-furnace practice. Moreover, the furnaces will be able to use a mixture of ordinary gas coke and coke breeze as reducing agents, instead of the higher-quality metallurgical coke required for the operation of ordinary blast-furnaces. For each ton of pig iron, the furnaces will produce about 20,000 cu. ft. of gas with a calorific value of 270 B.Th.U./cu. ft., which will cover all the reheating requirements of an integrated iron and steel works. The electric smelting furnaces will accordingly be less of a drain on the restricted coking coal and oil resources of the world than would a works based on blast-furnaces of the same capacity, and no scrap will be used. This new Norwegian enterprise should thus fit well into the present programme of European recovery.

The Electrochemical and Electrometallurgical Industry of Norway

By C. W. Eger

SYNOPSIS

The development of the electrochemical and electrometallurgical industry of Norway to its present-day proportions, since the beginning of the present century, has been made possible largely by the country's water-power resources and its many excellent ports. The country also has considerable mineral resources. The principal electrochemical and electrometallurgical plants, and their products, in the various industrial areas of Norway, are described, and it is concluded that further development of the industry can be expected when increased hydro-electric power is made available.

THE electrochemical and electrometallurgical industry of Norway is of vital importance to the export trade of that country. The industry dates from the beginning of the present century, when industrialists in Norway and elsewhere realized the potentialities of the country's large water-power resources and the numerous and excellent ice-free ports. This combination greatly favoured the development of hydro-electric power schemes and, as a result, the electrochemical and electrometallurgical industry. By 1939, hydro-electric plants in Norway had a total capacity of nearly three million kilowatts—a greater capacity per head of population than exists in any other country in the world. Apart from the normal applications of lighting, cooking, and heating, this electric power is used largely in the electrochemical and electrometallurgical industry. Before the war, this industry accounted for one-eighth of the total production value of Norway's industries.

DEVELOPMENT OF THE INDUSTRY

The first important steps toward the development of the industry were made during the years 1905 to 1912, when large plants were established for the fixation of atmospheric nitrogen. Examples of other processes which have been developed in Norway since then, are the nickel-refining process at Falconbridge, electric copper-smelting at Sulitjelma, and the Tysland-Hole electric pig-iron furnaces at Christiania Spigerverk and at Bremanger. The Tysland-Hole type of furnace, used for the electric processing of iron ores, was developed in Norway, and has since been built and operated successfully in a number of other countries. The well-known continuous self-baking Söderberg electrode, which was developed in Norway during the years immediately following the 1914–18 war, revolutionized the design of electric smelting furnaces and also of cells for the electrolysis of fused electrolytes. This type of electrode has been adopted by many industrial countries.

Figure 1 shows the chief industrial areas of Norway and the sites of the principal electrochemical and electrometallurgical plants which are mentioned in this paper.

MINERAL RESOURCES OF NORWAY

Deposits of iron ore are worked at Sör-Varanger and in other localities in the far north of Norway. The yearly output before 1939 was nearly 1½ million tons. Many deposits of pyrites exist, the most notable of which is at Orkla. The chief copper-mining areas are at Sulitjelma and at Röros. The largest European deposits of molybdenum- and titanium-bearing ores are in Norway; there are no coal deposits, although nearly half-a-million tons per year are mined at Svalbard.

ELECTROCHEMICAL AND ELECTROMETALLURGICAL PLANTS

The chief industrial concern of this type is Norsk Hydro-Elektrisk Kvælstofaktieselskab, with plants at Rjukan, Notodden, and Eidanger. The company was formed in 1905 for the purpose of converting atmospheric nitrogen into oxides by the Birkeland-Eyde process. Although initially successful, this process has since been replaced by the electrolytic production of hydrogen for the manufacture of synthetic ammonia. The ammonia is used for production of nitric acid and fertilizers. Sodium carbonate, heavy water, and inert gases, etc., are also produced, and nearly 100,000 tons of nitrogen are manufactured per year.

The company has a new plant under erection at Glomfjord, in the north, which by 1950 will increase the firm's present total output by about 50%.

The Southern Area

Apart from Norsk Hydro, most of the electrochemical and electrometallurgical plants are located along the coast. At the estuary of the River Glommen, near Sarpsborg, the power company of A/S Hafslund has, since 1899, operated a smelting works producing calcium carbide and ferro-silicon of all grades.

On the outskirts of Oslo are the steelworks of Christiania Spigerverk, where electric steel furnaces and rolling mills are operated and wire nails and agricultural implements are manufactured. This company operated the first Tysland-Hole furnace. The pig iron produced, which contained vanadium, was blown in an acid converter and vanadium slag was produced for export. This process was discontinued at these works in 1948, and was transferred on a much larger scale to Årdal, in the West of Norway.

At Strömmen are located the works of A/S Strömmens Værksted, which company has been making steel since 1902, and is the oldest steel-producing concern in Norway. The company is well known internationally for its steel castings.

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Mr. Eger is President of Elektrokemisk A/S, Oslo, Norway.

Two smaller electric steel producers in this area, Raufoss Ammunisjonsfabrikker and A/S Drammens Jernstöberi and mek Værksted, should also be mentioned.

At Porsgrunn, Porsgrunn Elektrometallurgiske A/S produce ferro-silicon and ferro-manganese in a modern plant which commenced operation in 1914. Nearby are the works of Heröya Elektrokjemiske Fabrikker A/S (HEFA) ; these works were inaugurated jointly in 1947 by the Norwegian State and Norsk Hydro, for the production of electrolytic chlorine, alkali, and hydrochloric acid.

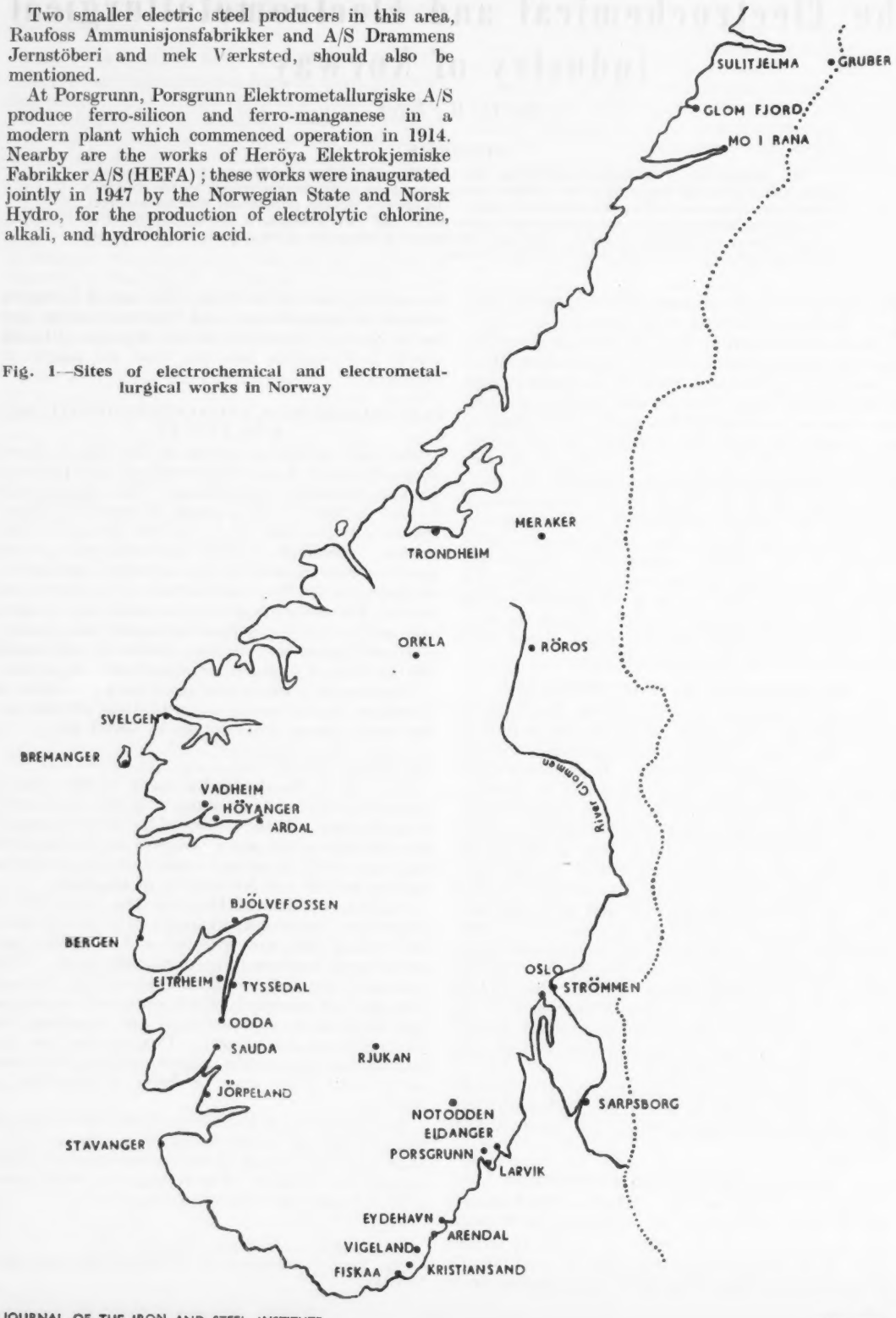

Fig. 1—Sites of electrochemical and electrometallurgical works in Norway

At Notodden, a short distance inland, are the calcium carbide plant of Notodden Calcium-Carbid-fabrik A/S and the ferro-alloy works of Tinfos Jern-verk A/S. At Larvik, Larvik Smelteverk A/S started the production of ferro-chromium shortly after 1945.

The next large industrial area on the southern coast is at Eydehavn, where an aluminium factory is operated by Det Norske Nitridaktieselskap A/S, based on imported alumina. A/S Arendal Smelteverk, situated nearby, is the largest producer in Europe of silicon carbide, and its 'Sika' products are well known.

A short distance to the north of Kristiansand are the aluminium works of A/S Vigelands Brug. Once producing aluminium, this plant is now engaged in the electrolytic refining of aluminium metal. On the outskirts of Kristiansand, the modern works of Falconbridge Nikkelverk A/S produce nickel on a large scale by electrolysis, concurrently with copper and precious metals. A/S Fiskaa Verk make ferro-alloys and electrode paste for Söderberg electrodes, both for home consumption and for export. This electrode was developed about thirty years ago at Fiskaa Verk by the parent company, Elektrokemisk A/S. The design of the Tysland-Hole electric pig-iron furnace was based on experiments conducted in the pilot plant at Fiskaa Verk.

The Western Coast

There are a great many industrial plants on the western coast of Norway. The most southerly of these is Stavanger Electro-Staalverk A/S, at Jörpeland, near Stavanger. This plant has maintained a high reputation for special steels since its foundation in 1912. Considerable extension and modernization is now being carried out at Jörpeland.

The largest ferro-alloy works in Norway, and one of the largest of its kind in the world, is the Electric Furnace Products Co., Ltd., at Sauda, where the chief product is ferro-manganese of various grades. The works commenced operation in 1923.

Among the many industries situated around the Hardangerfjord are the A/S Björlvefossen ferro-alloy works, which were started in 1918 and whose main products are ferro-silicon and ferro-chromium; Odda Smelteverk A/S, at Odda, is Norway's largest producer of calcium carbide, and the only manufacturer of calcium cyanamide, of which some 30,000–40,000 tons were exported annually before 1939.

Det Norske Zinkkompani A/S, at Eitrheim, near Odda, is the latest industrial enterprise in the electrochemical field. It has been in operation since 1929, and has a yearly output of approximately 45,000 tons of pure zinc and 140 tons of cadmium. The plant includes an up-to-date sulphuric acid plant, and extensions are now in hand to enable the sulphuric acid produced to be used for the manufacture of superphosphates.

Det Norske Nitridaktieselskap has another aluminium-producing plant, situated across the Söfjrord, at Tyssedal.

At Vadheim, in the Sognefjord, A/S Vadheim Elektrochemiske Fabriker produce potassium and sodium chlorates. At A/S Norsk Aluminium Company, at Höyanger, alumina is made by smelting bauxite in electric furnaces by the Pedersen process. The alumina is used in the company's aluminium plant, and the process also yields a high-grade pig iron as a by-product.

A new aluminium plant of 12,000 tons' capacity has recently been put into operation at Årdal, and also an electric pig-iron plant; both plants are operated by A/S Årdal Verk.

North of the Sognefjord, at Svelgen, are the works of A/S Bremanger Kraftselskab, which has for many years been producing pig iron electrically. Further north, in the Trondheim district, are two more smelting works, A/S Ila og Lilleby Smelteverker, near Trondheim, and A/S Meraker Smelteverk, near the Swedish border. Ferro-alloys are produced at the former, and ferro-alloys and calcium carbide at the latter.

The Northern Area

As already mentioned, a new plant is being erected at Glomfjord, in the north, by the Norsk Hydro company. Until recently, aluminium was produced in this district by A/S Haugvik Smelteverk.

A suitable site has been decided upon for the new Norwegian Iron and Steel Works, at Mo i Rana; production is planned to commence in 1953. Included in the works will be an electric pig-iron plant with a yearly output of 200,000 tons, and also electric steel furnaces and rolling mills. Operations will be based exclusively on home ores, and no scrap will be imported.

Finally, mention should be made of A/S Sulitjelma Gruber, who have been smelting their own ores to copper matte in electric furnaces since 1928.

CONCLUSION

The electrochemical and electrometallurgical plants of Norway are producing to the fullest extent with the power that is available; as new hydro-electric stations are erected so will production at existing plants be increased. In addition, new works may be built, but the present unsettled conditions make it difficult to forecast with accuracy any future developments. Apart from the expansion of the nitrogen industry and the erection of a new iron and steel works at Mo i Rana, an increase in capacity of the ferro-alloy and the aluminium industries is contemplated.

Power projects, both those at present under construction and those which are being planned, will involve much greater expense than would similar projects before the war. However, owing to the general rise in prices, the favourable relationship between power costs in Norway and those in most other countries, is likely to be maintained in the future. Furthermore, the output from most Norwegian power plants is constant throughout the year—a factor of considerable importance to the electrochemical and electrometallurgical industry. It is therefore reasonable to expect further expansion of this and other industries in Norway which are dependent upon the constant availability of large quantities of cheap power.

Some Notes on Brittleness in Mild Steel

By Johan Görrissen

SYNOPSIS

Brittle fracture in unkilled mild steel such as that used in chain manufacture was investigated with special reference to the effect of grain size and structure. It was confirmed that grain boundary cementite is not formed above the temperature of A_1, but is formed during slow cooling from A_3 to room temperature. It is essential to anneal above A_3 to avoid a coarse-grained ferrite structure. Fast cooling lowers the transition range temperature because of the finer ferrite grain size and more beneficial pearlite–cementite structure. Slow cooling-rates are detrimental to impact properties. Too fast cooling-rates may introduce embrittlement due to quench-ageing. Steels alloyed with 0·05 to 0·30% of silicon or 1·25 to 1·50% of manganese are considered more suitable than mild steel for chain-making. The addition of aluminium is beneficial in controlling grain size and reducing liability to ageing. Up to 0·25% of carbon does not affect the impact value.

Introduction

PROBLEMS related to brittle fracture in mild steel are today considered important, and have been dealt with in papers, published chiefly in American and English journals.[1, 2, 3, 4, 5] These papers, however, have been restricted largely either to investigations on the cause and prevention of brittle fracture in shipbuilding plates, or to the subject of brittle fracture derived from the angle of stress distribution around notches.

A comprehensive investigation of brittle fracture in mild-steel chains was begun at Christiania Spigerverk in 1939, as a consequence of the many failures on ship steering chains during the stormy winter season of 1937–1938—a contributing factor to the loss of several ships—and because mild-steel bars for chains are an important part of the firm's production schedule.

Until some years ago chains were largely manufactured in Norway by forgewelding of mild unkilled steels, especially from Swedish Lancashire iron. The making and repairing of chains with mild unkilled steels by blacksmiths is still the prevalent practice in Norway. Today, however, chains are increasingly produced of high-tensile steels by the electric flash-welding process.

Mild killed steel is especially susceptible to brittle fracture, which is an important and a grave problem, demonstrated by the fact that, on an average, one chain is broken every day in the harbour of Oslo.*

Even today we have little knowledge of the complex factors determining the behaviour of this type of steel, or of their relative importance. From the many publications dealing with this problem we may, however, predict that the following points are of major importance. The method of production gives the steel special characteristic properties, and it is known that acid steels as well as basic Bessemer steels are more liable to brittle fracture than is the corresponding open-hearth grade. It seems probable that this inherent property is due to the higher content of phosphorus, and especially of nitrogen, in the Bessemer steels. The susceptibility to ageing, which is a characteristic property of mild steels, can be affected by metallurgical processes such as deoxidation.

It is also well known that coarse grains and inferior microstructure introduced by low heat-treatment will increase the susceptibility to brittleness.

Although little is known about the importance of the distribution and the physical properties of slag inclusions, we must assume that they are detrimental to the properties of the steel, and that the effect is pronounced when the slag is partly soluble in the steel, as is the case with iron oxides.

Therefore, there are many factors which determine the susceptibility of a steel to break at a low impact value. The present investigations do not cover this entire field, but work has been limited mainly to the effect of the structure and grain size, and to some points which influence these factors.

MATERIAL INVESTIGATED

The effect of the content of phosphorus and nitrogen on the behaviour of mild steels[6] has not been dealt with in the present investigation, as the steels under test are all produced by the same metallurgical process, and these two elements are not present in amounts sufficient to be considered harmful.

Some of the steels investigated are basic electric steels taken from the regular production. Heats 9954 and 13382 are made by the scrap/pig-iron process. Heats A, B, and 32558, are made from 50% scrap and 50% pig iron blown down to 2·5% of carbon approximately, in an acid Tropenas converter.

The experimental heats are made in laboratory furnaces, either in an indirectly heated Junkers type, or in a high-frequency furnace, with steel of the same type and analysis as steel A, as raw material. (The analyses of the different steels are given later in the report.)

Grain Boundary Cementite

The formation of grain boundary cementite has been the subject of several papers: J. H. Whiteley[7] investigated the formation of cementite during annealing of quenched samples. In this case, the precipitation of cementite was found to be extremely rapid; for this apparently rapid diffusion of C in α-iron a probable explanation has not been given.

Kornfeld and Brieger[8] investigated the formation of grain boundary cementite in a mild killed steel previously reduced by cold work. The steels were

* Private communication from the Inspector of Safety, Port of Oslo.

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Mr. Görrissen is Director of Research at Christiania Spigerverk, Oslo, Norway.

subsequently annealed between A_1 and A_3, and cooled at a rate of 55° C./hr. The susceptibility to formation of grain boundary cementite was especially pronounced after 10–15% reduction by cold work, followed by annealing between 730° C. and 810° C.

Dobinsky and Hanemann[9] confirm that grain boundary cementite is formed by annealing between A_1 and A_3, on subsequent slow cooling. They also claim that this structure is formed by cooling in air from 750° C. The impact value, however, is not affected by this treatment. The cementite is preferably formed at the grain boundaries in fine-grained steels. With the same pearlite–cementite distribution no correlation between grain size and transition temperature was found.

R. L. Rickett and F. C. Kristufek[10] recently published an interesting paper dealing with the subject on the basis of microstructure and increase in hardness. Isothermal transformation curves indicate extremely rapid formation of grain boundary cementite in steels with a very low carbon content. The cementite is preferably formed on the grain boundaries either by precipitation from supersaturated α-iron, or from austenite. The size of the cementite grains depends upon the preceding treatment and the annealing temperature.

EXPERIMENTAL PROCEDURE

Several methods are suggested for the determination of brittleness in mild steels : Change in hardness, tensile test on notched specimens, notch bend test, notch impact test, and investigation of the cleavage. The dimensions of the specimens and the sharpness of the notch are important factors.

As chains regularly have a poor surface, with scratches and notches acting as stress raisers, notched impact test-pieces were used for the investigation. These were of the standard Charpy keyhole type, $10 \times 10 \times 55$ mm. A disadvantage of the Charpy test-piece is that no simple mathematical expression can be given for the stress distribution around the notch. The modified test-piece advocated by the Belgian engineer Mr. Schnadt, which overcomes this disadvantage, was not known at the time of these investigations.

The impact testing machine used was an Alpha impact testing machine of 10 kg.m. capacity. Where not otherwise stated, the testing was carried out at a temperature of + 20° C. For tests above and below room temperature the test-pieces were held for 10 min. at the temperature in question, and then quickly transferred to the testing machine. Low temperatures were obtained by mixing alcohol or acetone with dry ice.

Preliminary Tests

The material used in the following tests is steel *A*, an unkilled mild steel, of the following composition : C 0·058%, P 0·013%, S 0·032%, Mn 0·33%, N 0·0054%.

The purpose of these tests was to give a preliminary idea of whether the grain boundary cementite is formed above or below A_1.

In the first test the sample was normalized at 930° C., followed by air cooling. The cooling rate was found to be about 250° C./min. at 700° C. The structure was normal ferrite–pearlite as shown in Fig. 8. The impact value after normalizing was 18 kg.m./sq. cm.

By cooling slowly in the furnace from 930° C., the impact value was only 6·5 kg.m./sq. cm. It is therefore obvious that slow cooling favours a brittle structure. Kornfeld and Brieger state that grain boundary cementite is formed quickly after annealing just above A_1. Some test-pieces were therefore heated to 930° C., cooled to 740° C., and kept at this temperature for various lengths of time, followed by air cooling. This treatment, however, did not produce any difference in the ferrite–pearlite structure. The impact value was 18–19 kg.m./sq. cm. for all samples, regardless of the length of time they were kept at 740° C.

The next series was undertaken to investigate the possible effect of slow cooling from above A_1. The samples were heated to 930° C. and cooled, at a rate of 50° C./hr., to 740° C., at which temperature they were kept for 3 hr. They were then cooled to 720° C. at a rate of 50° C./hr., and cooled in air. Neither the impact value nor the structure was changed by this procedure.

These preliminary tests conducted on a previously normalized material indicate that under such conditions grain boundary cementite is not formed above A_1. Grain boundary cementite present in slowly cooled samples must therefore be formed at temperatures below A_1.

Isothermal Transformation

The preliminary tests have shown clearly that grain boundary cementite is formed during slow cooling from above A_3 to room temperature, and that the steel has a lower impact value after this treatment. In order to obtain information about the mechanism and temperature range of this reaction, samples were annealed at temperatures below A_1. The impact values and structures were determined for different lengths of time at the annealing temperature.

All tests were conducted on standard Charpy test-pieces, though it was realized that this test-piece is not the ideal one for investigation of rapid reactions, since the time required for uniform temperature distribution may be too long. The usefulness of a test-piece which at the same time could be used for the determination of the impact value was, however, considered of sufficient importance for use of the Charpy test-piece.

In all tests, the test-pieces were first annealed at 930° C., for 10 min. They were then quickly transferred to a comparatively large lead bath kept at the desired temperature. After various intervals, the samples were removed from the bath and cooled in air.

As the preliminary tests indicated that no grain boundary cementite is formed above A_1, additional tests were carried out at the following temperatures : 715°, 710°, 700°, 690°, 675°, 650°, and 600° C.

Annealing at a temperature of 690° C. resulted in a pronounced drop in impact value, whereas annealing at other temperatures from 710° to 600° C. caused only a slight reduction in impact value. It seems reasonable, therefore, to assume that the structure

developed at 690° C. is inferior to those resulting from other annealing temperatures.

All test-pieces were examined under the microscope. No precipitation of cementite apparently took place after annealing for 5 hr. at 715° C. The structure was still made up of ferrite and pearlite, similar to that obtained in normalizing. Annealing at 710° C. gave, on the other hand, an interesting picture of the cementite formation. After annealing for ½ hr. the structure was still ferrite and pearlite without any signs of cementite at the grain boundaries. After annealing for 10 hr. the structure was chiefly ferrite and pearlite, but in isolated spots the pearlite had decomposed completely, ejecting the cementite to the grain boundaries (Fig. 9).

The microstructures of samples annealed at 710° C. give a clear picture of the stability of pearlite at temperatures just below A_1. After annealing at 700° C. for 5 hr. the structure is composed of only ferrite and pearlite. After annealing for 10 hr. at the same temperature, however, a considerable quantity of cementite has been ejected to the grain boundaries.

At 690° C. the ejection of cementite to the grain boundaries takes place at a much faster rate. After annealing for 15 min. the decomposition of pearlite has started, and some cementite has been ejected to the grain boundaries (Fig. 10*a*). After annealing for 1 hr. the reaction has progressed considerably, the cementite lamellae being thicker, and the pearlite areas correspondingly smaller (Fig. 10*b*). After annealing for 7 hr. the pearlite has practically disappeared. The cementite appears by preference as heavy bands in the grain boundaries, an appearance considered typical of cementite formed by decomposition of pearlite (Fig. 10*c*). After an annealing time of 10 hr. the structure consists entirely of ferrite and grain boundary cementite.

Cementite bands as shown in Figs. 10 *a*, *b*, *c* are apparently of a less harmful type. The presence of heavy cementite bands means that the available quantity of cementite will not be sufficient to envelop the grains to such an extent that the impact value is seriously affected. Steel, however, is not a homogeneous material, and various types of cementite may be present at the same time. After annealing at 690° C. for 15 min., besides the structure indicated in Fig. 10*a*, an entirely different type of cementite has appeared in other areas in the same sample, as is shown in Fig. 10*d*. This is a typical grain boundary cementite which is formed apparently by precipitation from a supersaturated α-solution, and is typical of areas very low in carbon. It seems reasonable to assume that the impact value of the steel is reduced if a considerable amount of this particular type of boundary cementite is present.

At 675° C. the velocity of cementite formation is also very great. After 15 min. the greater part of the pearlite is decomposed to cementite, and after 3 hr., only small amounts of partly decomposed pearlite remain. Very long annealing periods—18 to 24 hr.—seem to develop a structure where the cementite at the grain boundary no longer forms continuous bands, but has coalesced, appearing as isolated spheroids along the grain boundaries.

It is apparent that if the annealing temperature is lowered to 650° C., the region of the very fast formation of grain boundary cementite is passed. Ten hours' annealing is required for complete transformation, and the cementite is formed in smaller grains, which are not elongated to any extent along the grain boundaries, as is the case with higher annealing temperatures.

At the lowest annealing temperature used in the investigation, 600° C., some grain boundary cementite appeared after 7 hr., but the cementite particles were very small and did not form continuous bands.

In evaluating the results it must be borne in mind that the material investigated is a mild unkilled steel containing 0·06% of carbon, since there are undoubtedly different reaction processes for steels with carbon content above and below the solubility limit in α-iron.

The tests have demonstrated that in low-carbon steel containing sufficient carbon to form a carbon-saturated austenitic phase, pearlite is first formed, which after long annealing is decomposed into cementite and ferrite. The appearance of the cementite at the grain boundary is accordingly dependent on the primary pearlite. Cementite bands formed by this reaction are thick and only partly enclose the grains. A long annealing period promotes a distinct spheroidizing of the cementite.

Although the carbon content of steel *A* is fairly low, most of the cementite is formed by decomposition of pearlite. The true grain boundary cementite appears only in areas of very low carbon content. It is therefore obvious that the formation of cementite in normalized steels with approximately 0·05% of C does not effect a serious reduction in impact value.

Thus the formation of grain boundary cementite as explained above does not fully agree with the explanation of direct transformation from austenite, as suggested by Rickett and Kristufek, but indicates a great stability of pearlite just below A_1, and that a development of cementite at the grain boundaries takes place between 675° and 690° C.

The approximate time which elapses before the cementite formation can be recognized and is completed, is given in a tentative diagram (Fig. 1). Since the rate of cementite formation is based on microscopical examination, it cannot be determined with any great accuracy, and is to a large extent dependent upon the personal skill of the observer, and upon the

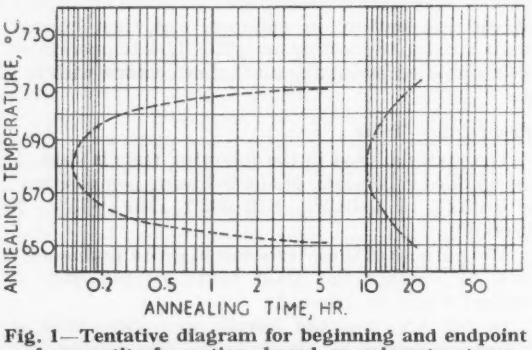

Fig. 1—Tentative diagram for beginning and endpoint of cementite formation, based on microstructures

resolving power of the microscope. The curves are not in agreement, apparently, with the observations made by Rickett and Kristufek, who found the maximum formation rate of cementite to be at about 450° C. Their material, however, contained only 0·02% of carbon, and the reaction investigated was obviously a different one, *viz.*, the precipitation of cementite from α-iron. It is apparent that the results recorded in Fig. 1 are more in accordance with the regular spheroidization of pearlite. The temperatures given for the maximum rate of cementite formation are in full agreement with those recommended for spheroidization of plain carbon steels. The influence of carbon content on the type of grain boundary cementite formed is now being investigated.

Although the impact value is not seriously reduced by isothermal annealing, it is obvious that such treatment has changed the character of the steel to a certain degree. An evaluation of the effect of various temperatures is obtained by comparison of the impact value and structure after annealing for 5 hr. The results are given in Figs. 2 and 11 *a*, *b*, *c*, *d*.

After annealing for 5 hr. at 700° C. the structure is still ferrite and pearlite. At 690° C. the annealing has transformed the pearlite entirely to coarse cementite grains. Annealing at 675° C. has also transformed most of the pearlite. Here the cementite, however, is largely distributed as small isolated grains along the grain boundaries. The ferrite grain size is slightly smaller than in the previous sample.

After annealing at 600° C. the pearlite is also largely transformed to cementite, but the grain sizes of both cementite and ferrite are definitely smaller than in the previous samples. The smaller ferrite grains are in all probability due to a faster cooling rate and the smaller cementite grains to a slower diffusion rate.

Supplementary tests were conducted to investigate if an intermediate anneal just below A_1 would lead to an increased brittleness. As this was not the case, it seems probable that α-iron becomes saturated with carbon during the rapid cooling from above A_1 to the isothermal annealing temperature.

Effect of Slow Cooling

Several specifications covering annealing of low-carbon steels prescribe that the steels should be heated to temperatures above A_3. The cooling rate, however, is not specified.

Since precipitation of cementite at the grain boundaries is one of the reasons for brittleness in mild steels, and since this precipitation takes place during slow cooling, it is of interest to determine the cooling rate required to prevent the formation of this particular form of cementite.

The following tests were made with steel *A* and are valid only for a steel of this type and composition. Results are shown in Fig. 3.

All samples were first given a homogenizing anneal at 930° C. for 10 min. They were then cooled in the furnace at an even rate from 930° C., removed at various temperatures, and allowed to cool in air. As previous tests have indicated that the formation of grain boundary cementite takes place above 640° C., it was not considered necessary to prolong the even rate of cooling lower than that. Results of some samples cooled to 550° C. confirm that no further drop in impact value occurs between 650° and 550° C.

One test series was cooled at a rate of 100° C./hr. directly down to 640° C., while the cooling of a second series was interrupted by an intermediate anneal at 710° C. for 1 hr. When the steel was held at 710° C. for 1 hr., the drop in impact value apparently occurred at a slightly higher temperature. The effect, however, is very small, and care should be taken in drawing too hasty conclusions from this difference.

Two more series were cooled at a rate of 50° C./hr. directly down to 640° C., the cooling of one series being interrupted by an intermediate anneal at 740° C. for 5 hr. Both series gave the same temperature/impact value correlation. The temperature range in which the steel, cooled at a rate of 100° C./hr., as well as at 50° C./hr., loses its impact toughness, is the same as that found by isothermal annealing.

At a cooling rate of 25° C./hr. the drop in impact value starts at a higher temperature than in the other series. This seems to indicate that the steel is more susceptible to cementite decomposition when cooled slowly through the A_1 range than when annealed isothermally. The total drop in impact value, however, is the same for cooling rates between 25° and 100° C./hr., and agrees with that obtained by isothermal annealing at 690° C.

The structure of the sample cooled at a rate of 25° C./hr. down to 710° C., followed by air cooling, was examined under the microscope (Fig. 12). No pearlite is to be found, and the ferrite–cementite structure of the sample explains its low impact value.

The microstructure of the samples cooled at a rate of 100° C./hr., followed by air cooling from 690° and 660° C., are shown in Figs. 13 and 14. After air

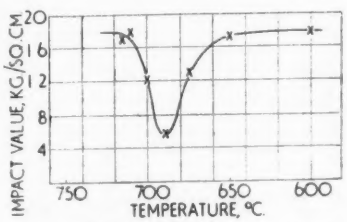

Fig. 2—After isothermal annealing for 5 hr.

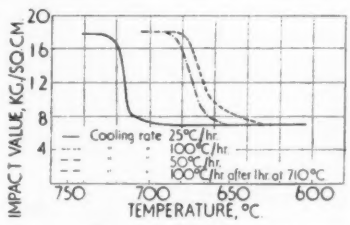

Fig. 3—After cooling at different rates from 930° C. to various temperatures

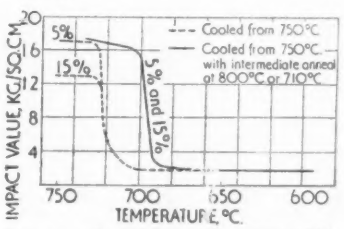

Fig. 4—After reduction 5 and 15% by cold work, annealed at 750° C., and cooled at 25° C./hr., with and without intermediate anneal at 800° or 710° C.

Figs. 2–4—Impact values at 20° C. for steel *A*

Note. Impact values should be shown in kg.m./sq. cm. units in these and following diagrams.

cooling from 690° C. the structure is chiefly pearlite and ferrite, with only minor cementite particles present. The lower impact value of the sample cooled in air from 660° C. may be fully explained by the appearance of pearlite, which is largely decomposed.

The tests conducted by slow cooling confirm that the ejection of cementite takes place at temperatures below A_1.

Slow Cooling of Steels Previously Reduced by Cold Work

A mild steel which is reduced 5 to 15% by cold work will recrystallize during a subsequent anneal, forming a coarse-grained structure. It is natural that a coarse-grained steel is in itself more brittle than is a fine-grained one. It is also probable that grain boundary cementite will promote a greater loss in impact value in coarse-grained steels.

The steel used in this series of tests was the same as in the previous test series (steel *A*). The steel was normalized before reducing the area 5 and 15% by cold work. The reduction was made by drawing the test-bar through a 10 × 10 mm. die. All tests were made on samples reduced both 5 and 15%.

In the first series, the test-pieces were heated to 800° C. and kept at this temperature for a sufficient length of time to obtain a thorough soaking, and then cooled at a rate of 25° C./hr. The samples were removed from the furnace at various temperature levels and cooled in air.

As shown in Fig. 4, the samples reduced 5% give a somewhat higher impact value than those reduced 15%. This is valid for samples air cooled from temperatures above A_1, and may be attributed to a difference in ferrite grain size, and not to formation of cementite. The loss in impact value started as soon as the temperature had dropped below A_1. After air cooling from lower temperatures there was no difference between samples reduced 5 and 15%.

The effect of intermediate annealing above and below A_1 was also investigated. As found in previous tests, an anneal just below A_1 has no effect. Annealing at 800° C. changes the temperature at which the drop in impact occurs to 700°, as compared with 720° C. in specimens not annealed.

The probable explanation is that a faster transformation occurs in samples not in equilibrium. A long anneal at 800° C. produces a specimen which is more fully homogenized and free from strains, and therefore the transformation is impeded.

The lower impact value of samples previously reduced by cold work as compared with those previously normalized is due to differences in grain size. The ferrite grain size is a dominating factor concerning the impact value.

IMPACT VALUE AND TEMPERATURE RELATION

The impact value in the tests described so far was determined on standard Charpy test-pieces broken at + 20° C. It is well known, however, that the impact value, especially of ferritic steels, is greatly influenced by the temperature.

It seemed probable that curves showing the impact value/temperature relation would give a more explicit picture of the properties of a steel than values obtained at + 20° C. alone. Steels having corresponding impact values at room temperature may have widely different transition temperatures. It seemed, therefore, desirable to extend the investigations to cover the variation in impact value with temperature.

The same material as in previous tests was used. Prior to the tests, the samples were all heated to 930° C. and kept at this temperature for about 10 min. for homogenization. They were cooled in air, and at the rates of 200°, 100°, 50°, and 25° C./hr. The slowly cooled samples were cooled at predetermined rates down to 600° C., at which temperature they were removed from the furnace and cooled in air to room temperature.

The results given in Fig. 5 indicate clearly the advantage of fast cooling. It is obvious that a pronounced improvement is achieved by cooling in air. Differences in cooling rates between 25° and 200° C./hr. have a remarkably small influence. The structures, Figs. 15 *a*, *b*, *c*, give a reasonable explanation of the curves in Fig. 5. As expected, the normalized sample consists of ferrite and pearlite. After slow cooling the grain size is much coarser than that of the normalized sample, and the pearlite is partly decomposed to cementite. The negligible difference in structure between the various slowly cooled specimens is in agreement with the impact/temperature curves.

Impact Value of Steels Previously Reduced 10% by Cold Work

The preceding investigation into the properties of steels previously reduced by cold work, has demonstrated their low impact value at 20° C. This fact is accentuated by the impact/temperature curve in Fig. 6, and it is important to notice that cooling in air does not give a steel of satisfactory impact value at 0° C.

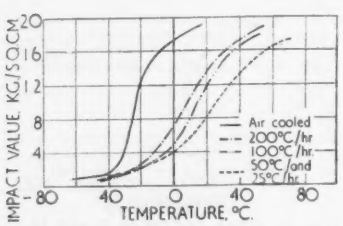

Fig. 5—Annealed at 930° C., cooled at various rates

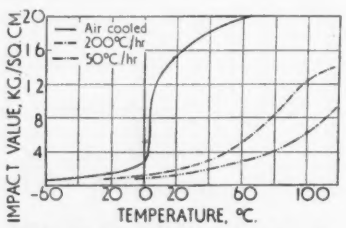

Fig. 6—Reduced 10% by cold work, annealed at 740° C., cooled at various rates

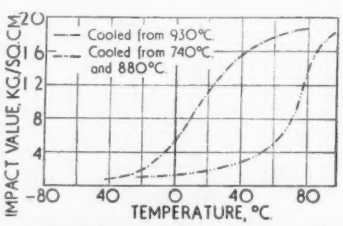

Fig. 7—Reduced 10% by cold work, annealed at various temperatures, cooled at 100° C./hr.

Figs. 5–7—Impact values of steel *A* after various treatments

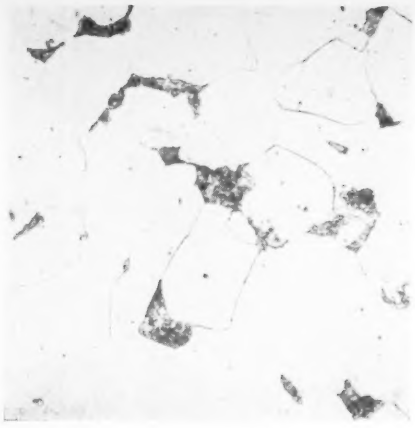

Fig. 8—Heat A. Normalized × 580

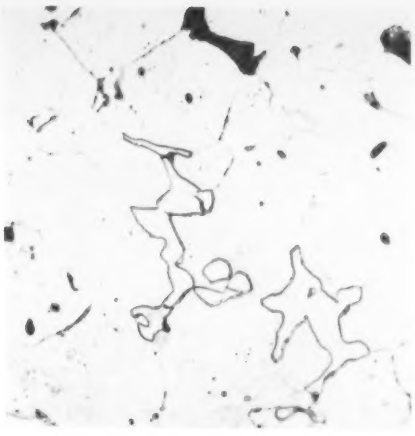

Fig. 9—5 hr. at 710° C. × 580

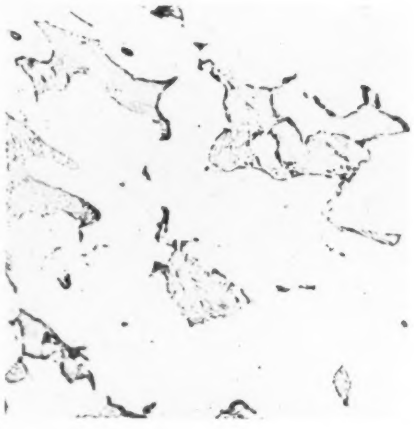

Fig. 10 (a)—690° C. for 15 min. × 580

Fig. 10 (b)—690° C. for 1 hr. × 580

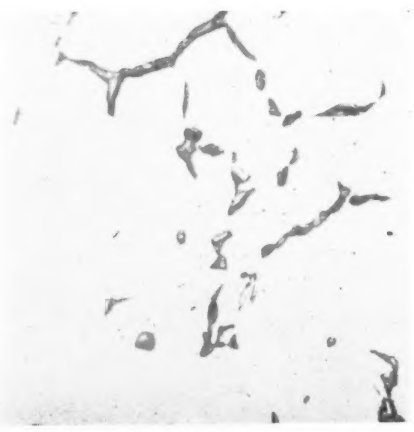

Fig. 10 (c)—690° C. for 7 hr. × 580

Fig. 10 (d)—690° C. for 15 min. × 1750

Figs. 9 and 10—Heat A. Annealed for various times at different temperatures. Figs. 9 and 10(d) etched in nital. Figs. 10 (a), (b), (c) etched in sodium picrate

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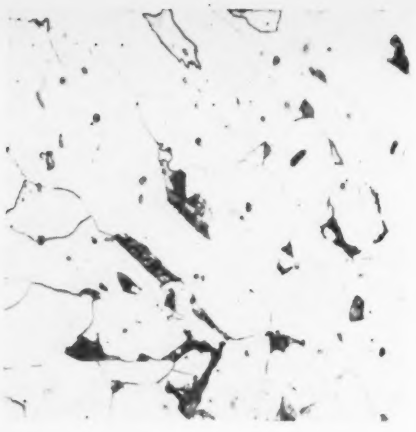

Fig. 11 (a)—700° C. × 580

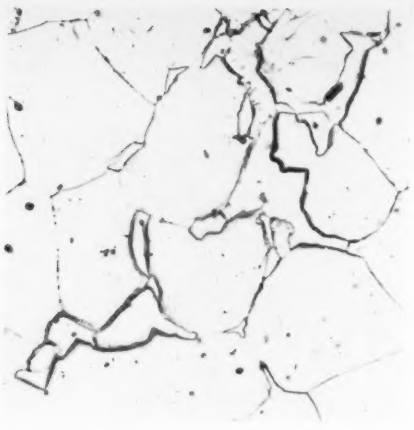

Fig. 11 (b)—690° C. × 580

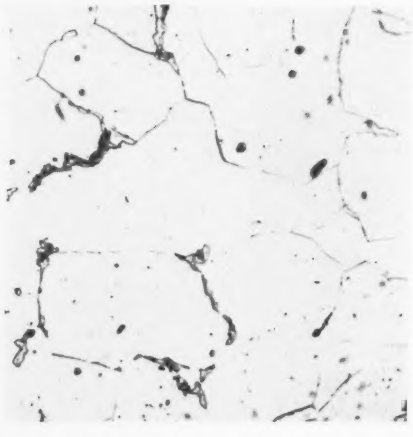

Fig. 11 (c)—675° C. × 580

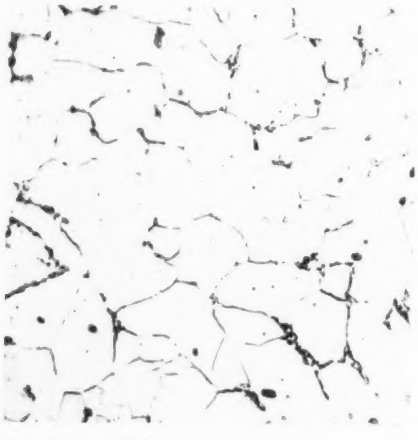

Fig. 11 (d)—600° C. × 580

Fig. 11—Heat A. Annealed at various temperatures for 5 hr. Etched in nital

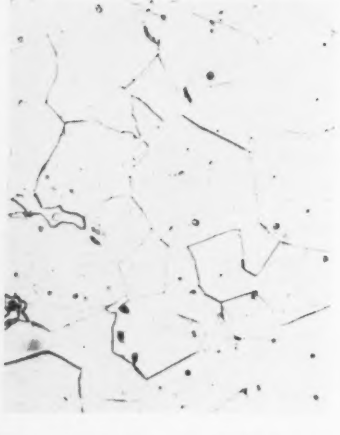

Fig. 12—Cooled to 710° C. at 25° C./hr. × 580

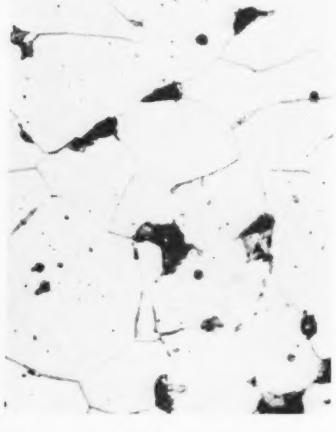

Fig. 13—Cooled to 690° C. at 100° C./hr. × 580

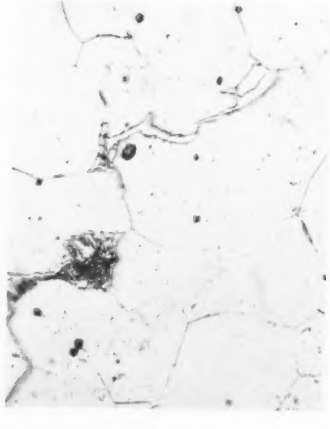

Fig. 14—Cooled to 660° C. at 100° C./hr. × 580

Figs. 12 to 14—Heat A. Annealed at 930° C., cooled to various temperatures at various rates, then cooled in air. Etched in nital

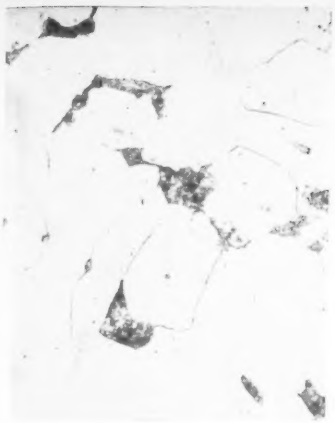

Fig. 15 (a)—Cooled in air × 580

Fig. 15 (b)—Cooled at 100° C./hr. × 580

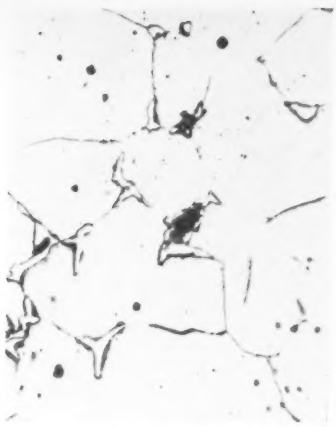

Fig. 15 (c)—Cooled at 25° C./hr. × 580

Fig. 15—Heat A. Annealed at 930° C. Etched in nital

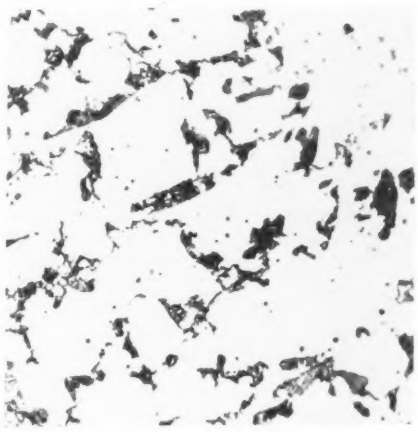

Fig. 16 (a)—Cooled in air, annealed at 750° C. × 580

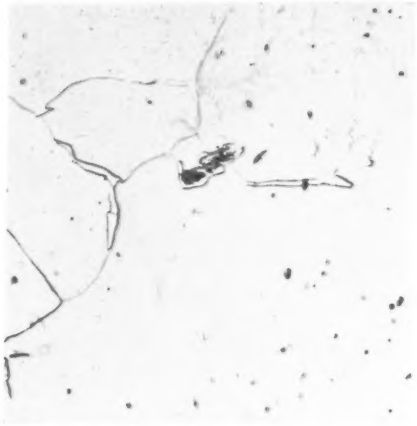

Fig. 16 (b)—Cooled at 200° C./hr., annealed at 750° C. × 580

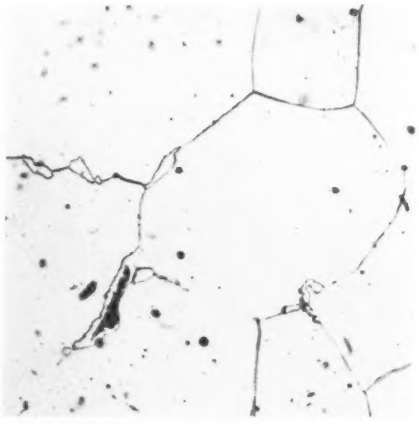

Fig. 16 (c)—Cooled at 50° C./hr., annealed at 750° C. × 580

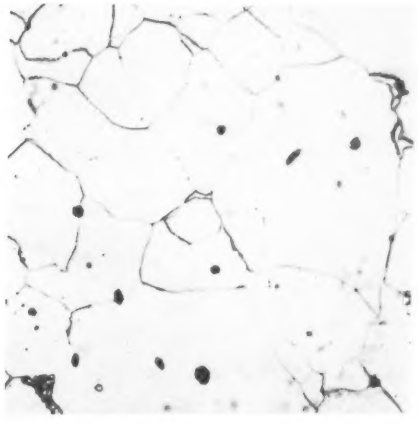

Fig. 16 (d)—Cooled at 100° C./hr., annealed at 880° C. × 580

Fig. 16—Heat A. Reduced 10% by cold work, annealed, cooled at various rates

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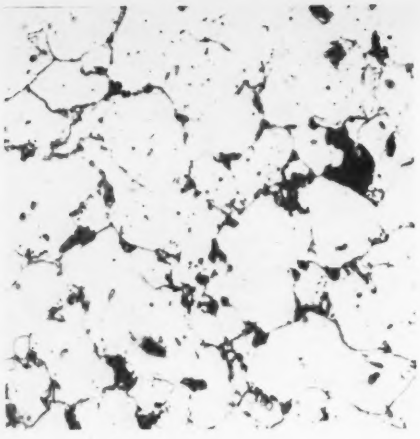

Fig. 17 (a)—Cooled in air × 580

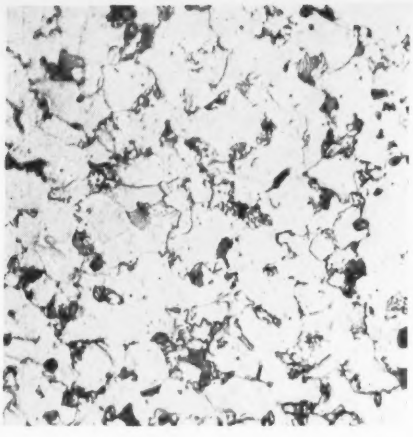

Fig. 18 (a)—Cooled in air × 580

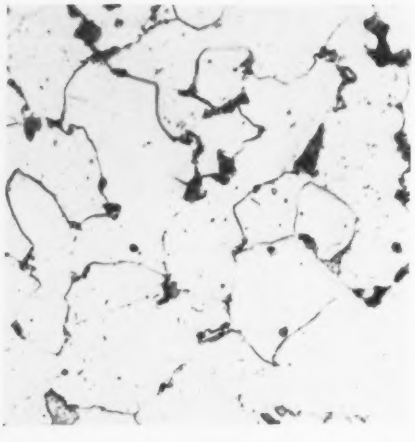

Fig. 17 (b)—Cooled at 200° C./hr. × 580

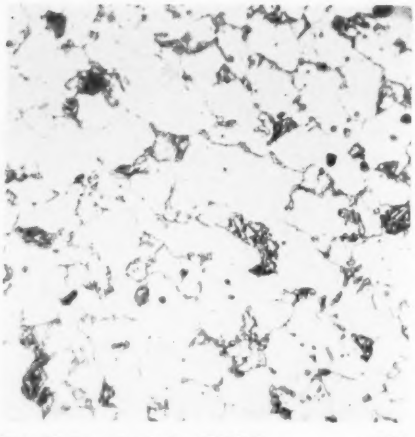

Fig. 18 (b)—Cooled at 200° C. × 580

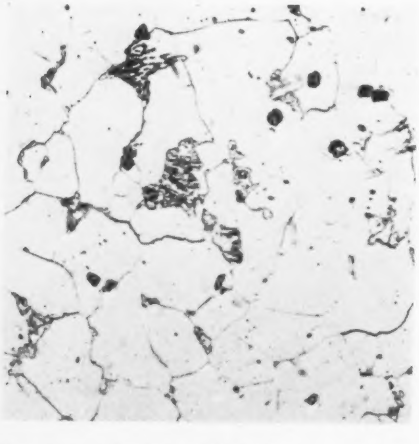

Fig. 17 (c)—Cooled at 50° C./hr. × 580

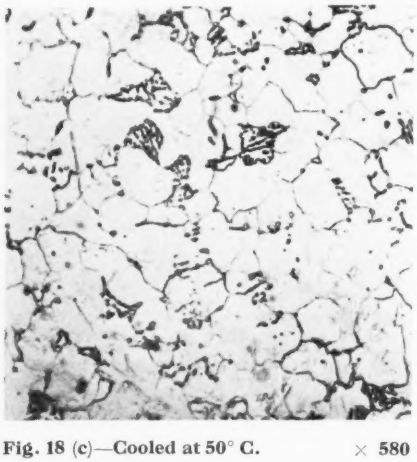

Fig. 18 (c)—Cooled at 50° C. × 580

Figs. 17 and 18—Heat 13382. Reduced 10% by cold work, annealed at 750° C., cooled at various rates. Fig. 17, no aluminium. Fig. 18, 300g./ton aluminium. Etched in nital

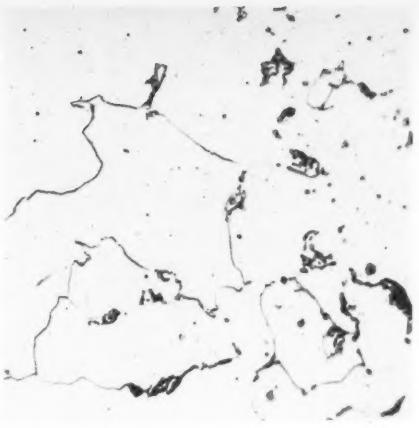

Fig. 19 (a)—Cooled in air × 580

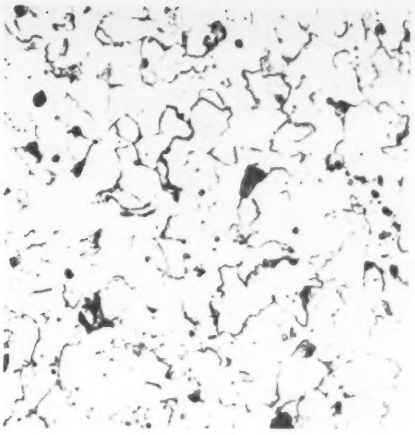

Fig. 20(a)—Cooled in air

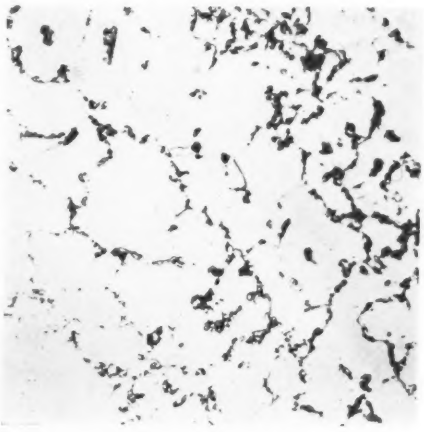

Fig. 19(b)—Cooled at 200° C./hr. × 580

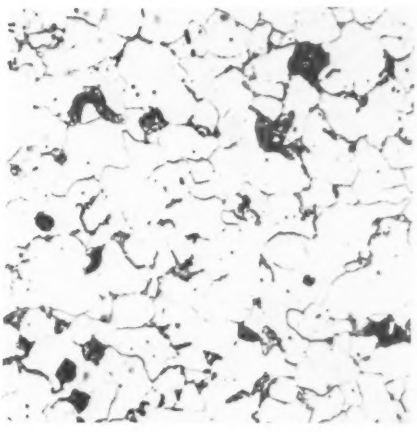

Fig. 20(b)—Cooled at 200° C./ hr.

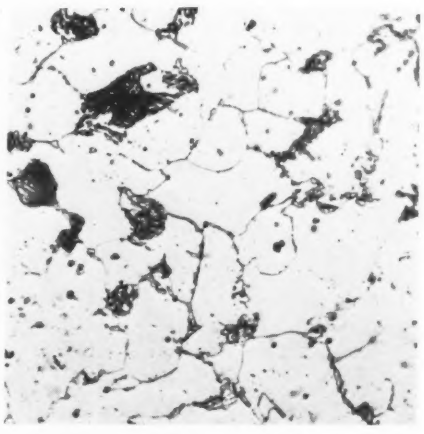

Fig. 19 (c)—Cooled at 50° C./hr. × 580

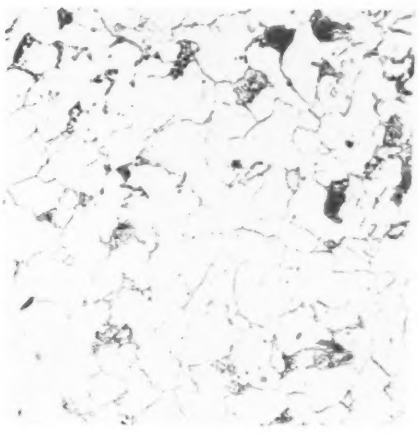

Fig. 20(c)—Cooled at 50° C. hr.

Figs. 19 and 20—Heat 9954. Reduced 10% by cold work, annealed at 750° C., cooled at various rates. Fig. 19 no aluminium : Fig. 20—300g/ton aluminium addition Etched in nital

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Fig. 21 (a)—Heat G34/1 × 580

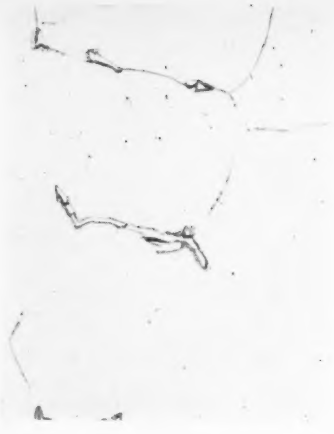

Fig. 21 (b)—Heat G31/1 × 580

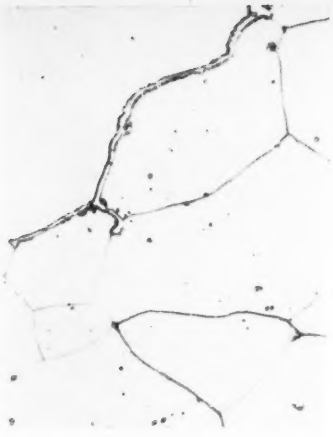

Fig. 21 (c)—Heat H37 × 580

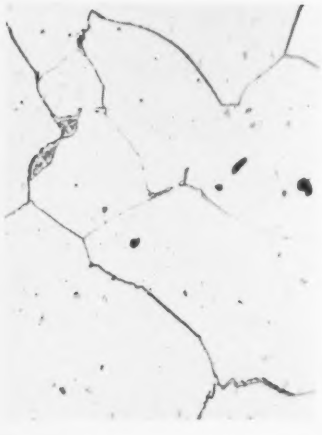

Fig. 21(d) —Heat H74 × 580

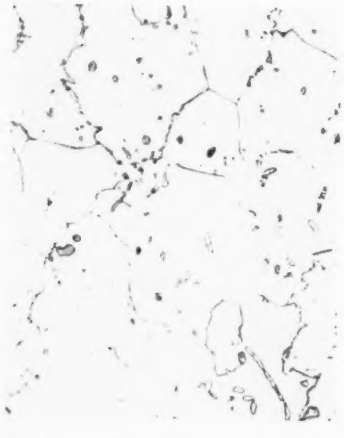

Fig. 21 (e)—Heat H75 × 580

Fig. 21—No silicon, increasing manganese. Reduced by cold work 10%, annealed at 740° C., cooled at 50° C./hr.

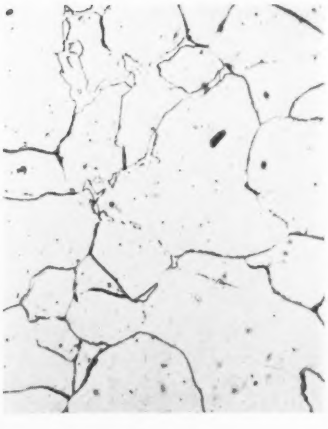

Fig. 22 (a)—Heat G34/2 × 580

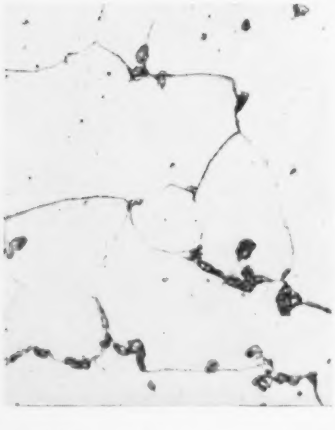

Fig. 22 (b)—Heat H5 ×580

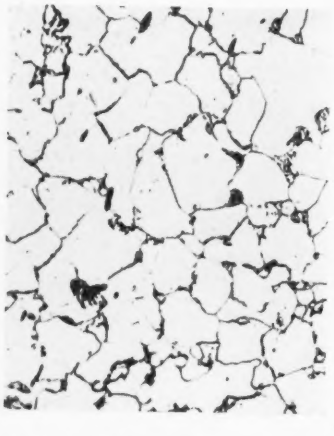

Fig. 22 (c)—Heat G35 × 580

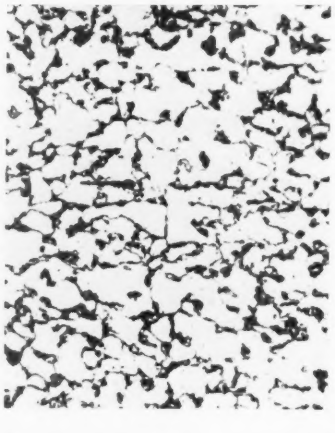

Fig. 22 (d)—Heat G39 × 580

Fig. 22—Low silicon, increasing manganese. Reduced 10% by cold work, annealed at 740° C. and cooled at 50° C./hr. Etched in nital

Fig. 23 (a)—Heat H73 × 580

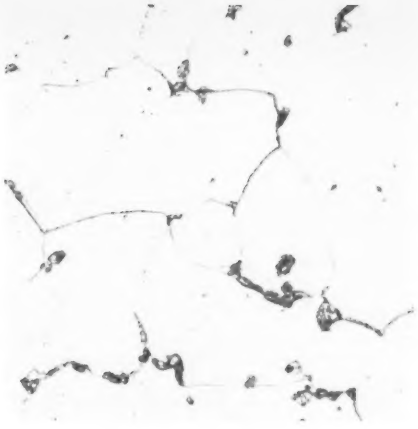

Fig. 23(b)—Heat H5 × 580

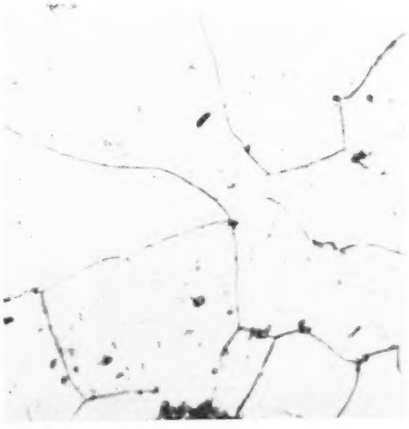

Fig. 23 (c)—Heat H4 × 580

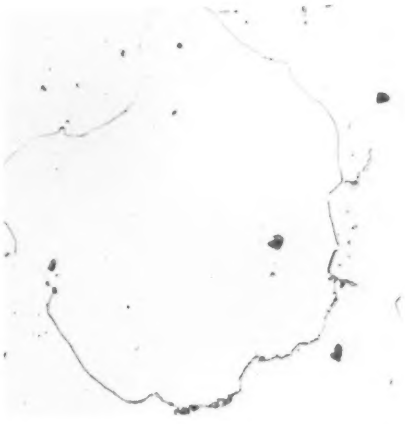

Fig. 23 (d)—Heat H7 × 580

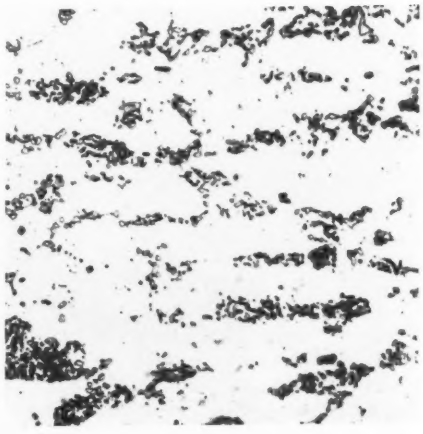

Fig. 23 (e)—Heat H17 × 580

Fig. 23—Increasing silicon, approx. 0·75% manganese. Reduced 10% by cold work, annealed at 740° C., cooled at 50° C./hr. Etched in nital

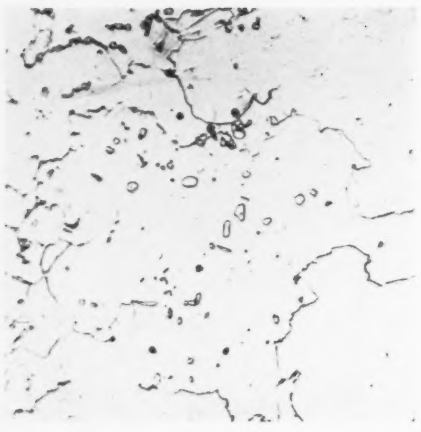

Fig. 24 (a)—Heat H70 × 580

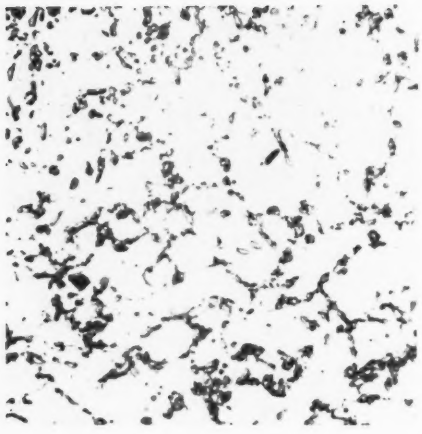

Fig. 24 (b)—Heat H40 × 580

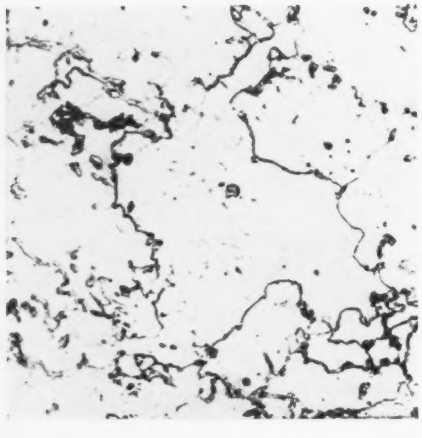

Fig. 24 (c)—Heat H66 × 580

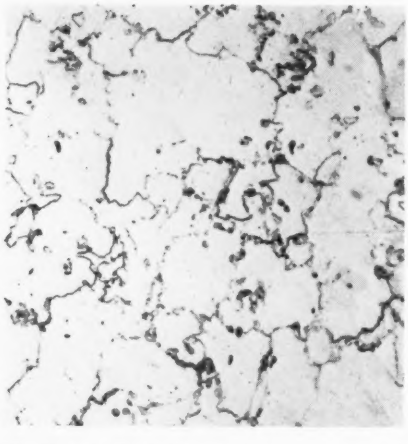

Fig. 24 (d)—Heat H41 × 580

Fig. 24—Increasing silicon, approx. 1·50% manganese. Reduced 10% by cold work, annealed at 740° C., cooled at 50° C./hr. Etched in nital

The impact/temperature curve for this rate of cooling strikingly illustrates the negligible value of a single test carried out at 20° C. Tested at this temperature the steel is apparently of good quality, although it is extremely brittle at zero. Curves of this type are by no means infrequent. From Figs. 5 and 6, it is obvious that steels previously reduced by cold work are more influenced by the cooling rate than are steels cooled from above A_3.

The microstructures of steel samples reduced by cold work and subsequently cooled from 750° C., respectively in air and at a rate of 200° and 50° C./hr., are demonstrated in Figs. 16 *a*, *b*, *c*. After air cooling, pearlite and ferrite only are visible ; slow cooling, on the other hand, produces a structure consisting of ferrite and cementite, with traces only of nearly transformed pearlite.

Of still greater importance, perhaps, is the heavy increase in grain size of the slowly cooled specimens. A considerable difference in structure will be observed between air cooled and slowly cooled specimens but little or no variation between samples cooled at the rates of 200° and 50° C./hr. Again, the microstructures are in agreement with the impact/temperature curves in Fig. 6.

A question of practical importance is the temperature required to re-establish a high impact value of a steel reduced by cold work.

Chains, for instance, must be considered as reduced in service. In annealing specifications for this material, temperatures between A_1 and A_3 are often recommended. It seems, however, doubtful whether these specifications are made with due consideration to the complexity of steel. Thus, test-pieces previously reduced 10% by cold work are heated to 740°, 880°, and 930° C., respectively, and cooled at a rate of 100° C./hr. As shown in Fig. 7, the impact temperature curves after annealing at 740° C. and 880° C. are identical, and very poor.

The microstructure of the sample annealed at 880° C. might seem more favourable than of that annealed at 740° C. ; nevertheless, it consists of a mixture of small and large grains (Fig. 16*d*). Measured by the J.K.M. standard, the grain size varies between 10 and 15.

After heating to 930° C., however, the impact value is much better, and the quality corresponds to that of a normalized steel. Subsequently, it was evident that annealing temperatures above A_3 are required.

INVESTIGATION OF STRUCTURE AND IMPACT PROPERTIES OF SOME MILD STEELS

The following tests were conducted on two unkilled mild steels of standard composition.

A chain of 1½ in. dia., which had failed in service with a typical brittle fracture, was tested. This steel, steel *B*, had the following composition : C 0·03%, P 0·011%, S 0·036%, Mn 0·26%.

The impact value of the steel as received is given in curve No. I, Fig. 25, from which it is obvious that at + 40° C. the steel has lost most of its impact value. Several methods of heat-treating were tried, to improve the impact value. The heat-treatment used was annealing at 930° C., followed by cooling in air, oil, and water, respectively.

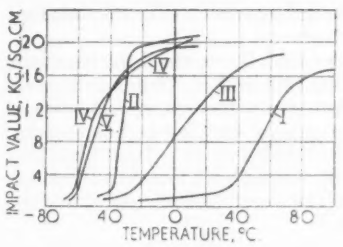

Fig. 25

Fig. 26

Fig. 25—Steel *B*. Impact values after various treatments. Curve No. I, as received; curve No. II, annealed at 930° C., then cooled in air; curves Nos. III and IV, annealed at 930° C., then oil-quenched; curve No. V, annealed at 930° C., then water quenched

Fig. 26—Location of test-pieces in cross-section of bar

The temperature/impact curves after various treatments are given in curves Nos. II–V in Fig. 25. It will be noticed that there are two curves representing oil-quenched samples. The reason for this is the unexpected poor properties obtained in the first series. The next series quenched in oil did, however, give a curve co-ordinating with the other results.

The structures of samples from all series were determined and were as follows :

Material	*Structure*
As received (curve No. I)	Ferrite–pearlite and some grain boundary cementite. Grain size : J.K.M. 13
Cooled in air (curve No. II)	Ferrite–pearlite and a little grain boundary cementite, especially in areas low in C. J.K.M. 13
Cooled in oil (curve No. III)	Same structure as in the previous sample. J.K.M. 10
Cooled in oil (curve No. IV)	As before. Grain size only a little finer. J.K.M. 8·8
Cooled in water (curve No. V)	Ferrite–pearlite and a minor quantity of grain boundary cementite. J.K.M. 10.

The ferrite grain size is quoted in J.K.M. numbers according to the standard grain size charts of the "Jernkontoret."*

The structure in samples from the different series is very much the same. The amount of grain boundary cementite does not differ so much that this alone can explain the difference in transition temperature. The coarse ferrite grain size in the samples having the highest transition temperature indicates its detrimental effect. It is, however, obvious that the faster cooling rate obtained by water quenching produces a material of better quality than can be obtained by a slower cooling rate, provided that there is the same ferrite grain size in both steels. This is probably due to a more beneficial grain boundary structure, although the difference is not visible under the microscope.

It is remarkable that steel taken from the same chain has different grain sizes after the same heat-treatment, as is the case with the two series quenched in oil. The explanation is probably a previous reduction of the chain by cold work which leads to a different coarse grain size during the subsequent

* These charts, which give the ferrite grain size, are considered superior to the A.S.T.M. Standard.

heating. A single annealing above A_3 is not sufficient to equalize the grain size.

The investigation of steel *B* confirmed the beneficial effect of a fast cooling rate and of a fine ferrite grain size, and shows that grain boundary cementite is preferably formed in areas of very low carbon content, as in the rim-zone in unkilled steels. Grain boundary cementite is evidently formed with very great velocity in such steels. In the core, pearlite only, and no cementite, is visible.

The investigation also indicates a strong influence of the carbon content on structure and properties, and it was considered of interest to extend these investigations. In order to keep the other variable factors as constant as possible, the samples were taken from different locations in the cross-section of an unkilled steel bar.

The steel used is melt 32558, having the following average composition : C 0·05%, P 0·014%, S 0·021%, Mn 0·025%.

The samples were cut from a 93-mm. dia. bar in the manner indicated in Fig. 26. The compositions of samples I, II, and III were :

Sample	C, %	P, %	S, %	Mn, %	N, %
I	0·025	0·011	0·012	0·20	0·003
II	0·050	0·011	0·054	0·23	0·004
III	0·058	0·015	0·078	0·25	0·006

The impact properties of samples I, II, and III were determined as-rolled, and after cooling of the 93-mm. bar from 930° C. in air, oil, and water, respectively, as well as of normalized Charpy test-pieces. The results obtained are illustrated in Figs. 27–31. The microscopical structures of the different samples are described in the following :

Material	*Structure*
Sample I (as-rolled)	Very low in C. Some grain boundary cementite and a negligible quantity of pearlite. Grain size : J.K.M. 12.
Sample II (as-rolled)	A little pearlite. Some cementite lamellæ, presumably formed by decomposition of pearlite. J.K.M. 11·5.
Sample III (as-rolled)	A little more pearlite than in sample II. A little cementite. J.K.M. 12.
Sample I (cooled in air)	Very low in C. Some grain boundary cementite. J.K.M. 12·25.
Sample II (cooled in air)	A little pearlite. Some cementite lamellæ and grain boundary cementite in areas low in C. J.K.M. 11.
Sample III (cooled in air)	A little more pearlite than in sample II. A little cementite. J.K.M. 10.
Sample I (cooled in oil)	Very low in C. Some grain boundary cementite and a negligible quantity of pearlite. J.K.M. 12·25.
Sample II (cooled in oil)	Some pearlite and a small amount of cementite. J.K.M. 10·25.
Sample III (cooled in oil)	Some more pearlite than in sample II. Cementite is not visible. J.K.M. 9·5.
Sample I (cooled in water)	A small quantity of fine-grained pearlite and some isolated grain boundary cementite. J.K.M. 10.
Sample II (cooled in water)	Approximately the same structure as in sample I, but a little more pearlite and cementite. J.K.M. 9·2.
Sample III (cooled in water)	Some more pearlite, a few cementite lamellæ and a negligible quantity of grain boundary cementite. J.K.M. 9.
Sample I (normalized as Charpy test-piece)	Very low in C. A little grain boundary cementite. Pearlite is not visible. J.K.M. 11.
Sample II (normalized as Charpy test-piece)	A little more grain boundary cementite than in sample I. A small amount of pearlite. J.K.M. 11·5.
Sample III (normalized as Charpy test-piece)	A comparatively large amount of pearlite, and a negligible quantity of grain boundary cementite. J.K.M. 10.

As expected, the samples taken from the core have a higher carbon content than the samples taken from the rim zone, and, accordingly, the pearlite–cementite relation is changed in the same order. It is also

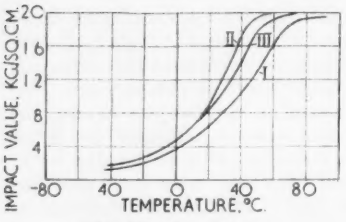

Fig. 27—As-rolled

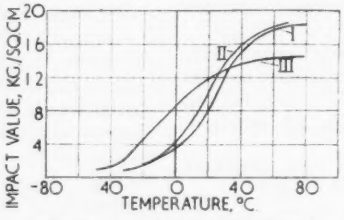

Fig. 28—Normalized condition

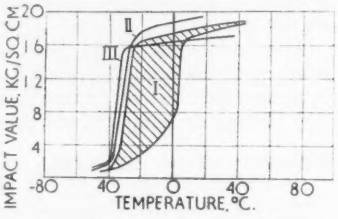

Fig. 29—After oil-quenching

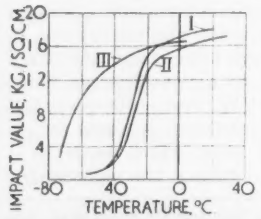

Fig. 30—After water-quenching

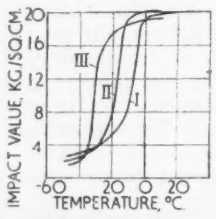

Fig. 31—Normalized as standard Charpy 10 × 10 × 55 mm. test-pieces

Figs. 27–31—Steel 32558. Impact values of samples I, II, III, after various treatments

obvious that a faster cooling rate and a higher concentration of impurities, including carbon, promote a finer grain size.

The impact values given in Figs. 27–31 indicate that there is only a slight difference between the properties of the steel as-rolled and normalized. There is also a small difference between samples taken from different locations in the bar. Normalizing, which corresponds to a cooling rate of about 1000° C./hr., improved the properties, especially of sample II, which is explained by its finer grain size.

Quenching in oil introduced markedly improved properties. Samples taken from the rim-zone had rather varying impact values, as indicated by the hatched space in Fig. 29. This type of transition curve is, however, not infrequently found, which may be due partly to the character of the test, and partly to varying structure and grain size.

The still faster cooling rate, obtained by quenching in water, results in better properties of the core and also in the disappearance of the scattering in impact of samples taken from the rim-zone, but does not improve the results very much beyond those obtained by oil quenching. The grain size is also approximately unchanged after these two rates of cooling.

Heat-treatment of chains is, however, mostly performed on steels of a smaller dimension than 93 mm. dia. For comparison, samples I, II, and III have therefore been normalized as standard Charpy test-pieces. The results given in Fig. 31 are the same as were found in the other series, that is, a lower transition temperature in the impure core as compared with the pure rim-zone.

In comparing the impact values with the structure, it is apparent that the great differences in pearlite–cementite structure do not correspond to great differences in impact value. The ferrite grain size is probably of greater importance than the structure itself. A fast cooling-rate is, however, of greater importance than can be deduced from the structure alone.

The investigation of this melt has confirmed that with the same heat-treatment the highest transition temperature is found in the softest and cleanest steels. The regular practice of using extremely mild steels for chains, based on their high elongation, determined by regular tensile test, seems to be very questionable.

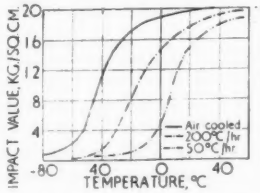

Fig. 32—No aluminium

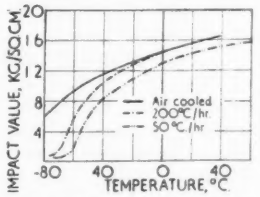

Fig. 33—300 g./ton aluminium

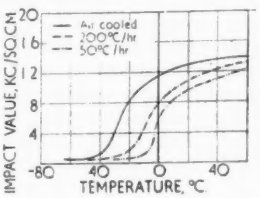

Fig. 34—No aluminium

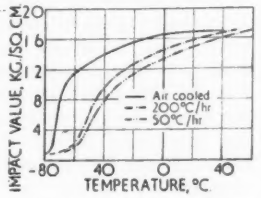

Fig. 35—300 g./ton aluminium

Figs. 32 and 33—Steel 13382. Figs. 34 and 35—Steel 9954. Reduced 10% by cold work, annealed at 740° C. and cooled at various rates

Steels Alloyed with Manganese and Silicon

All investigations referred to so far have been conducted on mild unkilled steels. It is beyond doubt that under favourable conditions also such steels lose a major part of their toughness at the low winter temperatures experienced in Norway. It is also evident that a slight change in heat-treatment conditions may alter the transition range to temperatures above zero.

It is well known that a strong deoxidation makes steel less susceptible to ageing. It is, however, not known how it affects the tendency of the steels to embrittlement after poor heat-treatment. In the papers by Barr and co-workers it is shown that manganese has a beneficial effect in this respect. Their investigations, however, are limited to this element only.

Preliminary investigations were conducted on two heats taken from the regular production. The melts were selected in order to investigate the effect of an increasing order of deoxidation. In this connection both melts were tested without, and with, the addition of aluminium, 300 g./ton, to the moulds.

The heats were treated in a manner which previous investigations had indicated as important. The treatment was a 10% reduction by cold work with subsequent annealing at 740° C., followed by slow cooling. For the sake of comparison, cooling in air was used as well as cooling rates of 200° and 50° C./hr.

The following heats were used for the investigation :

	Heat 13382 %	Heat 9954 %
C	0·09	0·18
P	0·016	0·021
S	0·040	0·026
Mn	0·54	0·55
Si	0·20	0·23

The impact/temperature curves after the various cooling rates are given in Figs. 32–35, and the corresponding microstructures in Figs. 17–20.

The difference between steel *A* and heat 13382 is that the latter is killed and has a somewhat higher Mn content. The properties and structures are, however, entirely different from those of the unkilled steel. As is apparent from the microstructures, the coarse structure which is typical for an unkilled steel is changed into a far more finely grained one. That the stronger deoxidation has had a favourable influence on the impact properties is seen by comparison with Fig. 6, which gives the properties of an unkilled steel after the same treatment. If, besides silicon and manganese, aluminium is added to the steel, the effect is still more pronounced, as is shown in Fig. 33.

Heat 9954, with a somewhat higher carbon content, has approximately the same properties as heat 13382. The beneficial effect of an aluminium addition is the same as in the previous heat. The impact values are only slightly lower than those obtained on the lower carbon material.

The microstructures give valuable information

regarding the difference between rimmed and deoxidized steels.

As there is little or no difference between the structure in the heats 13382 and 9954, they will be discussed together. By comparing steel *A* with the steel deoxidized with silicon alone, the structures after cooling in air in both cases show ferrite and pearlite (Figs. 16*a*, 17*a*, and 19*a*). The killed steels are, however, more finely grained than the unkilled ones. After slow cooling this difference is much more pronounced. Although traces of cementite are visible in the killed steels, the decomposition is not far progressed, the cementite being present chiefly as globules. The difference in structure is, however, not limited to the cementite, but is just as pronounced in grain size. Unlike unkilled steels, where a slow cooling rate promotes a coarse structure, killed steels only demonstrate a slight difference in grain size, whether cooled slowly or cooled in air.

If aluminium is added to steels killed with silicon, the grain size is definitely finer after all three rates of cooling.

The investigation of heats 13382 and 9954 has indicated the possibility of improving the impact values at low temperatures by alloying with manganese, silicon, and aluminium. In the following investigations the influence of manganese and silicon only is considered.

Altogether more than a hundred experimental heats were investigated, but only a limited number, forming certain series, will be discussed. The compositions of the heats were as follows:

Composition of Experimental Heats

Heat	C, %	Mn, %	Si, %	N, %
G34/1	0·06	0·26	...	...
G31/1	0·15	0·66	...	...
H73	0·07	0·72	...	0·007
H74	0·07	0·98	...	0·0042
H75	0·08	1·23	...	0·011
G34/2	0·10	0·27	0·06	...
H5	0·05	0·75	0·06	0·064
G35	0·14	1·04	0·03	...
G39	0·20	1·58	0·09	...
H73	0·07	0·72	...	0·007
H5	0·05	0·75	0·06	0·0064
H4	0·04	0·72	0·11	0·005
H7	0·045	0·73	0·25	0·007
H17	0·25	0·77	0·24	0·005
H70	0·08	1·47	0·16	0·0054
H40	0·06	1·50	0·21	0·006
H66	0·08	1·44	0·30	0·010
H41	0·06	1·48	0·40	0·0066

In the first series the effect of an increasing content of Mn in steel not containing silicon was investigated. Heat G34/1, with 0·26% of Mn, showed a normal rimming. Heat G31/1, with 0·66% of Mn, and H73, with 0·73%, both rose slightly in the mould, forming a cauliflower top. Heats with a still higher Mn content were entirely killed.

The impact values after 10% reduction by cold work followed by annealing at 740° C., and subsequent cooling at a rate of 50° C./hr. are given in Fig. 36, which shows the beneficial effect of an increasing Mn content.

Figures 21 *a*, *b*, *c*, *d*, *e* give the corresponding microstructures. Heat G34/1 (Fig. 21*a*) has a similar structure to steel *A* after the same treatment (Fig. 16*e*).

The effect of an increasing manganese content is to make the steels still more fine-grained. The transition temperatures of the different heats, as demonstrated in Fig. 36, correspond to the variations in grain size. The differences between the low manganese heat, G34/1, the high manganese heats, G31/1, H73, and H74, and the very high manganese heat, H75, are striking. Heat H75, with 1·23% of manganese, has a structure characterized by the presence of cementite globules instead of bands.

The next series includes steels killed with a small amount of silicon to which is added an increasing percentage of manganese. The impact/temperature curves are given in Fig. 37. The results, as compared with melts not killed with silicon, are most pronounced with a low manganese content. Heats G34/1 and G34/2, which are cast from the same heat, the difference being only a small addition of silicon, have different impact values. With manganese contents above 1% the effect of silicon addition is less pronounced.

The microstructures are reproduced in Figs. 22 *a*, *b*, *c*, *d*. Heat G34/2 has a somewhat finer grain size than would be anticipated from those of the other heats. Any definite explanation cannot be given but the high oxygen content prior to deoxidation may be responsible for a higher content of impurities, with an impairing effect on the impact value.

The two series quoted so far, indicated an improving effect of both manganese and silicon, especially regarding the impact properties at low temperatures. Therefore, the specific effect of silicon was investigated in the following two series.

In Fig. 38 are quoted the results obtained on steels containing approximately 0·75% of manganese, and silicon between 0 and 0·24%. The tests indicate a considerable difference in properties with the slightest addition of silicon (0·06%). A further increase in silicon has no effect. The curve representing melt H17, with 0·25% of carbon, is not illustrated, as it conforms with the other curves representing the silicon-killed melts.

The corresponding microstructures are reproduced in Figs. 23 *a*, *b*, *c*, *d*, *e*. Heat H73 is more coarsely grained than the heats killed with silicon, the difference, however, is not as marked as in heats of lower manganese content. Heat H17, containing 0·25% of carbon, has a higher percentage of carbides, present as spheroids and not as bands, as in steels of lower manganese content.

In the next series manganese is increased to about 1·5%, and the silicon content varies between 0 and 0·40%. The impact/temperature curves shown in Fig. 39 indicate that these steels have satisfactory impact properties in spite of a poor heat-treatment. An increasing silicon content has a good effect, although not so outstanding as has a low manganese content.

The corresponding microstructures are given in Figs. 24 *a*, *b*, *c*, *d*. It is apparent that with this high manganese content the carbides are present in a spheroidized form as in steels not killed by silicon.

An increasing content of silicon showed the same grain refining action mentioned above.

Our investigations have indicated the beneficial effect of both manganese and silicon in moving the transition range to lower temperatures. The effect of manganese is, however, more pronounced than that of silicon.

It is obvious that a high manganese content affects the grain growth during the annealing process of steels previously reduced by cold work. The recrystallization diagram of mild steels is accordingly influenced by alloying with manganese.

The investigations have shown that steels can be produced commercially in qualities not susceptible to brittleness initiated by a poor heat-treatment of the type explained above, and that the steels should contain 1·25 to 1·5% Mn. and 0·05 to 0·30% Si. A favourable effect of still higher percentages has not been found. A carbon content of up to 0·25% has no apparent effect on the impact values. So far, the investigations have covered only a few of the points connected with brittleness in mild steels. Other problems, such as ageing and welding properties, had also to be considered before the composition of an entirely foolproof steel could be proposed.

Therefore, several steels, including the experimental heats, were tested for strain ageing properties. Having undergone a 10% reduction by cold work, the samples were subjected to an artificial ageing process at 200° C. The impact curves were favourably influenced by the manganese and silicon present, but these two components alone did not allow for a transfer of transition temperature to much below zero.

Thus, by adding aluminium to the silicon–manganese alloyed steels a marked improvement was reached, giving—in the aged condition—transition temperatures down to 50° C. below zero.

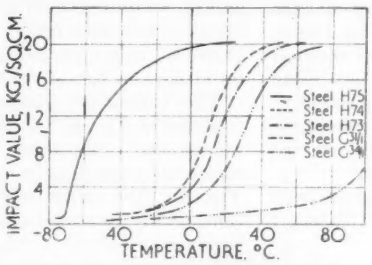

Fig. 36—No silicon, increasing manganese

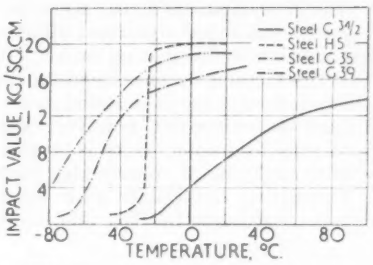

Fig. 37—Low silicon, increasing manganese

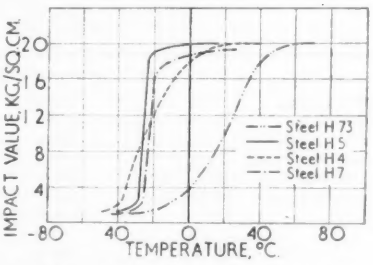

Fig. 38—Approx. 0·75% manganese, increasing silicon

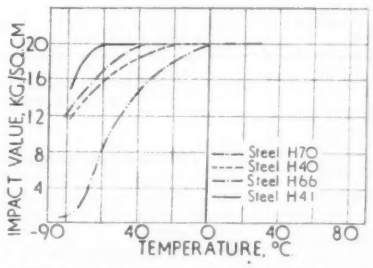

Fig. 39—Approx. 1·50% manganese, increasing silicon

Figs. 36–39—Impact values of steels with various amounts of silicon and manganese, reduced 10% by cold working, annealed at 740° C., cooled at 50° C./hr.

Thus, by adding aluminium to the silicon–manganese alloyed steels a marked improvement was reached, giving—in the aged condition—transition temperatures down to 50° C. below zero.

FURTHER POINTS INFLUENCING THE TRANSITION RANGE

As has already been stated, the ferrite grain size is an important factor in controlling the transition range. This observation is not a new one, Barr and Tipper quoted to that effect, though they were of the opinion that it was partly due to changes in microstructure introduced by the treatment. Barr and Honeyman agree to a higher transition temperature in coarse-grained steels, but they estimate the effect to be of a smaller magnitude than that of the Mn/C-ratio. The same authors also state that a high manganese content has a much stronger effect than the fine grain size promoted by an addition of aluminium. Their results were obtained on normalized steels.

In Fig. 40, the transition temperature with corresponding grain size according to our investigations, are illustrated, together with values deduced from the microphotographs published by Barr *et al.*

There is obviously a correlation between grain size and transition temperature, although the observations vary within a certain range of error. This scattering is not astonishing, as the impact value is affected also by components other than the grain size; the composition of the steel, as well as impurities and variations in the pearlite–cementite structure, must be taken into consideration. As already reported, the impact values obtained on fast cooling are better than would be anticipated from the grain size.

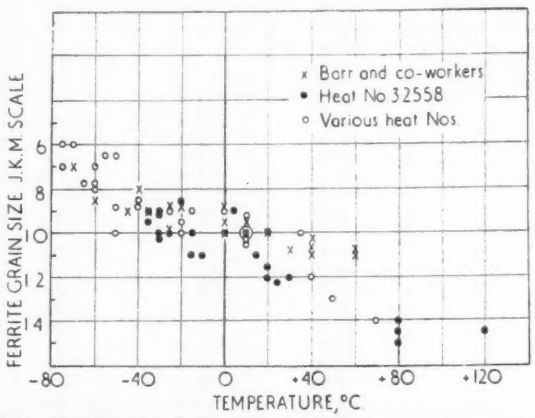

Fig. 40—Relation between transition temperature and ferrite grain-size in J.K.M. scale

The investigations have, however, indicated that regardless of other structural differences, the ferrite grain size is a dominating factor. It is our opinion that this factor is the most important one in controlling the transition range in annealed steels. The possibility cannot be overlooked, however, that the spheroidic cementite formation, which is typical for fine-grained steels, might be of considerable importance.

Comparing our results with those deduced from the investigations by Barr and co-workers, Tables I and II, we notice that for transition ranges above room temperature they found a somewhat finer grain size. Possibly, this may be due to a higher percentage of impurities or to a detrimental structure.

The transition temperature *vs.* the Mn/C ratio, is given in Fig. 41. It is apparent that an increased manganese content has a beneficial effect, but the relation is not nearly so evident as is the case in Fig. 40. The values representing heat No. 32558 are noteworthy in so far as they have several transition

Table I

GRAIN SIZE, Mn/C RATIO, AND TRANSITION TEMPERATURE RELATIONS

Heat	Treatment	Grain Size, J.K.M. Scale	Mn/C Ratio	Transition Range, °C.
A	Annealed 930° C., cooled in air	8·5	5·7	− 20
,,	,, ,, cooling rate 200° C./hr.	10·0	,,	+ 10
,,	,, ,, ,, ,, 100° C./hr.	10·0	,,	+ 20
,,	,, ,, ,, ,, 50° C./hr.	10·0	,,	+ 35
,,	10% reduced, annealed 740° C., cooled in air	9·0	,,	+ 5
,,	,, ,, ,, 740° C., cooling rate 200° C./hr.	14·5	,,	+ 80
,,	,, ,, ,, 740° C., cooling rate 50° C./hr.	14·5	,,	+ 120
B	As received	13·0	8·7	+ 50
,,	Normalized	9·0	,,	− 35
,,	930° C., cooled in oil	10·0	,,	+ 10
,,	,, ,, ,, ,,	8·8	,,	− 50
,,	,, ,, ,, water	10·0	,,	− 50
32588	As-rolled 95 mm. dia. (1)	12·0	5·0	+ 30
,,	,, ,, (2)	11·5	,,	+ 20
,,	,, ,, (3)	12·0	,,	+ 20
,,	Normalized 95 mm. dia. (1)	12·25	,,	+ 25
,,	,, ,, (2)	11·0	,,	+ 15
,,	,, ,, (3)	10·0	,,	0
,,	Cooled in oil 95 mm. dia. (1)	10·0	,,	0 to − 30
,,	,, ,, ,, ,, (2)	10·25	,,	− 30
,,	,, ,, ,, ,, (3)	9·5	,,	− 35
,,	,, ,, water 95 mm. dia. (1)	10·0	,,	− 25
,,	,, ,, ,, ,, (2)	9·2	,,	− 30
,,	,, ,, ,, ,, (3)	9·0	,,	− 30
,,	Normalized 10 mm. dia. (1)	11·0	,,	− 10
,,	,, ,, (2)	11·0	,,	− 15
,,	,, ,, (3)	10·0	,,	− 30
,,	10% reduced, annealed 750° C., cooling rate 50° C./hr.	15·0	,,	+ 80
,,	,, ,, ,, ,, ,, ,, 100° C./hr.	14·0	,,	+ 80
9954/0	,, ,, ,, ,, cooled in air	8·5	2·4	− 20
,,	,, ,, ,, ,, cooling rate 200° C./hr.	8·5	,,	− 10
,,	,, ,, ,, ,, ,, ,, 50° C./hr.	8·5	,,	0
9954/3	,, ,, ,, ,, cooled in air	6·5	,,	− 70
,,	,, ,, ,, ,, cooling rate 200° C./hr.	6·5	,,	− 50
,,	,, ,, ,, ,, ,, ,, 50° C./hr.	6·5	,,	− 45
13382/0	,, ,, ,, ,, cooled in air	8·75	6·0	− 40
,,	,, ,, ,, ,, cooling rate 200° C./hr.	9·0	,,	− 15
,,	,, ,, ,, ,, ,, ,, 50° C./hr.	9·25	,,	+ 10
13382/3	,, ,, ,, ,, cooled in air	6·0	,,	− 75
,,	,, ,, ,, ,, cooling rate 200° C./hr.	6·5	,,	− 55
,,	,, ,, ,, ,, ,, ,, 50° C./hr.	6·5	,,	− 50
G34/1	,, ,, ,, 740° C., ,, ,, 50° C./hr.	14·0	4·3	+ 70
G31/1	,, ,, ,, ,, ,, ,, ,,	12·0	4·4	+ 40
H73	,, ,, ,, ,, ,, ,, ,,	10·5	10·3	+ 10
H74	,, ,, ,, ,, ,, ,, ,,	10·0	14·0	+ 10
H75	,, ,, ,, ,, ,, ,, ,,	8·0	15·4	− 60
G34/2	,, ,, ,, ,, ,, ,, ,,	9·0	2·7	0
H5	,, ,, ,, ,, ,, ,, ,,	9·0	15·0	− 25
G35	,, ,, ,, ,, ,, ,, ,,	7·0	7·4	− 60
G39	,, ,, ,, ,, ,, ,, ,,	6·0	7·9	− 70
H73	,, ,, ,, ,, ,, ,, ,,	10·5	10·3	+ 10
H5	,, ,, ,, ,, ,, ,, ,,	9·0	15·0	− 25
H4	,, ,, ,, ,, ,, ,, ,,	9·5	18·0	− 20
H7	,, ,, ,, ,, ,, ,, ,,	10·0	16·4	− 20
H17	,, ,, ,, ,, ,, ,, ,,	9·0	3·1	− 25
H70	,, ,, ,, ,, ,, ,, ,,	8·5	18·3	− 40
H40	,, ,, ,, ,, ,, ,, ,,	7·75	25·0	− 60
H66	,, ,, ,, ,, ,, ,, ,,	7·75	18·0	− 65
H41	,, ,, ,, ,, ,, ,, ,,	7·0	24·6	− 75

temperatures with the same Mn/C ratio. If, on the other hand, the values representing this heat are equated against the grain-size, as in Fig. 40, they are well within the limit of error.

Therefore we consider it more correct to specify a certain maximum grain size instead of a minimum Mn/C ratio.

Formation of Grain Boundary Cementite

Whiteley, Hanemann, and others, have explained the formation of grain boundary cementite as a precipitation from a supersaturated α-solution. Besides this true grain boundary cementite, cementite may be formed by decomposition of pearlite.

The present investigations confirm these two different types of cementite: One which appears as thin bands along the grain boundaries in areas low in carbon content, and the other present as thick bands, globules or flakes, formed by decomposition of pearlite. The velocity of formation is rather different for these two types of cementite. Although the decomposition of pearlite progresses slowly, cementite bands in carbon-lean areas are visible also after a very fast cooling. It is obvious, therefore, that the reactions leading to grain boundary cementite are different in both cases.

The slow rate of ejection of cementite from pearlite is easily explained by a diffusion process. This explanation is not valid for the precipitation of cementite from α-iron, since the rate of diffusion necessary to explain the fast formation would be unique and not in accordance with the low solubility of carbon in α-iron. This difficulty has brought about theories of a rather doubtful nature.

The fast precipitation rate for grain boundary cementite indicates more of a lattice reaction than a diffusion process. Recent X-ray investigations have proved that dislocations are present in the outer layers of otherwise perfect metal crystals.* The logical consequence is to assume that the carbon in solution in the α-lattice is concentrated in lattice dislocations along the boundaries. A small amount may also be found in dislocation areas within the crystal lattice.

By increasing the temperature the increased activity of the atoms in the crystal lattice provides for an increased solubility of carbon.

As the carbon, according to this theory, is already concentrated in the soluble state near the grain boundaries, it is not necessary to assume a diffusion process in order to bring it to the spot of precipitation. It seems reasonable to assume that the proposed theory is valid not only for carbon, but also for other elements which preferably precipitate along the grain boundaries, and it provides a logical explanation for their precipitation at the boundaries and not within the grains.

Steels containing more carbon than can be held in solution in the dislocations in the outer layers of atoms will, on cooling, form a carbon-rich austenite which transforms to pearlite. Pearlite will then act as nucleation centres, attracting the carbon in solution in the adjacent lattice. This explains the fact that pearlite and grain boundary cementite are not present in the same location.

In accepting the theory of exclusive solubility of carbon in the outer layers of atoms, it is apparent that the limit of solubility is higher in fine-grained than in coarse-grained steels. Another consequence is that the curve in the iron–carbon diagram indicating the solubility of carbon in ferrite has a limited validity only, and in its present form indicates the average solubility only. It is, however, the solubility in the outer layers of atoms that is responsible for the formation of grain boundary cementite, and the solubility at this point is much higher than that indicated by the average percentage. It is also obvious that the variation in solubility with temperature is much higher than that indicated by the present solubility curve.

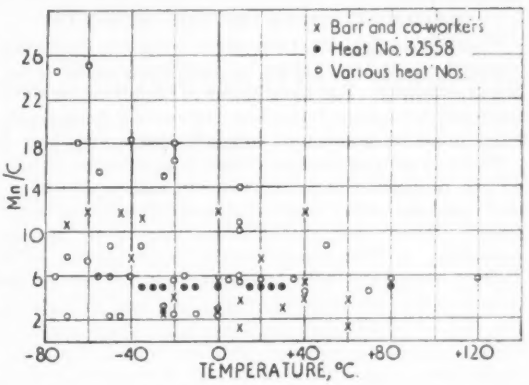

Fig. 41—Relation between transition temperature and manganese carbon ratio

Table II

GRAIN SIZE, Mn/C RATIO, AND TRANSITION TEMPERATURE RELATIONS

(According to Barr et al.[3, 4])

Steel	Grain Size, J.K.M. Scale	Mn/C Ratio	Transition Range, °C.
1229	11·00	1·4	+60
,,	10·00		+10
1230	10·25	4·0	+40
,,	8·75		−20
1278	10·00	7·8	−20
,,	8·00		−40
1232 (880° C.)	10·00	11·9	0
,,	8·50		−60
1232 (950° C.)	11·00	11·9	+40
,,	9·00		−45
1228	10·75	3·0	+30
,,	9·75		−25
1231	10·75	4·7	+40
,,	8·75		0
1233	10·75	3·9	+60
,,	9·50		+10
1261A	9·00	11·2	−35
1261B	7·00	10·6	−70
1262A	9·50	2·5	0
1262B	8·75		−25

* Private communication from Professor Finbak, Technical University of Norway, Trondheim.

PRACTICAL VALUE OF THE RESULTS

These investigations have given evidence that mild unkilled steels are subject to brittleness after poor heat-treatment. For their practical application their tendency to ageing as well as the correct heat-treatment must be taken into consideration.

These investigations have been concentrated chiefly on the properties and behaviour of chains which are still predominantly manufactured of unkilled mild steels. That such chains often have poor impact properties is illustrated by the investigation of a broken chain (Fig. 42). Assuming that the brittleness is caused by poor heat-treatment and not by ageing, the impact values of this particular chain conform with those of an unkilled, previously reduced steel, subjected to annealing between A_1 and A_3, with subsequent cooling in air.

Bearing in mind the facilities often available for annealing of chains, the result described above is not astonishing.[11] Responsibility for damage to the steel must, however, be shared by the classification

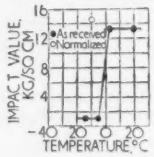

Fig. 42—Impact value of chain broken in service

institutions which permit chains to be annealed in wood fires, to burn off the tar in order to facilitate an inspection of the surface.

It is not surprising that poor annealing cycles are practised when, according to the A.I.S.E. Standard No. 4, Sling and Crane Chain Standards,[12] the specification recommends that wrought iron chains should be annealed every six months or otherwise when the chains are elongated 1 in. in 3 ft., the annealing temperature being 730° C. to 745° C., and followed by cooling in air. As chains in most cases are reduced by cold work, the transition temperature after treatment as above will be around 0° C.

In connection with the treatment of chains, should be mentioned the present incorrect practice of testing above the yielding point, whereby the chains are considerably weakened. A tensile test is undoubtedly important in order to ensure good and reliable welds, but it should be followed by an annealing process eliminating the effect of a plastic deformation. With the present practice the chains, when delivered from manufacturers, are already considerably weakened.

If, for some reason, unkilled steel should still be preferred as material for chains, etc., it is evident that the processing must be chosen in accordance with the inherent properties of this material.

CONCLUSIONS

These investigations indicate the importance of the following points :

(1) In practice chains are subject to severe handling with a consequent reduction by cold work. On subsequent annealing at temperatures below A_3 they are accordingly susceptible to grain growth. Hence it is essential that the annealing operation is performed at temperatures *above* A_3 to avoid a coarse ferrite structure.

(2) The cooling rate is also an important factor. By fast cooling rates the transition range temperature is lowered, partly due to a finer ferrite grain size and partly to a more beneficial pearlite–cementite structure. Slow cooling rates, which are sometimes advocated for mild steels, are detrimental to the impact properties, and should be abandoned. Cooling in air is somewhat better, but the best results are achieved by cooling in oil or in water. For practical use oil is to be preferred, since it provides a certain protection against corrosion.

(3) Although fairly good results are obtainable by annealing above A_3, followed by a fast cooling, the unkilled mild steels are not considered as ideal chain materials. The transition range is too easily transferred to higher temperatures. A too fast cooling rate may also introduce embrittlement due to quench ageing.

There are, therefore, good reasons for the introduction of a new steel of a quality less susceptible to brittleness. Such steels can be produced by alloying with silicon and manganese. With a silicon content of 0·05–0·30% the manganese content is preferably between 1·25 and 1·50%. Carbon up to 0·25% does not seem to affect the impact value. Aluminium has also a marked and beneficial effect, both in controlling the grain size and in reducing the liability to ageing.

Fine-grained steels, as specified above, include so many decided advantages that they should be used for chains and other constructional elements where a high impact value at low temperatures is essential.

Acknowledgments

The author wishes to express his sincere thanks to Christiania Spigerverk, for permission to publish the results obtained.

He is, furthermore, very much indebted to his co-workers, Messrs. H. Wintermark, Chr. Wefring, and K. Fjeldstad, for their never-failing interest and valuable co-operation.

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Determination of an Isothermal Transformation Diagram with an Optical Dilatometer

By J. K. L. Andersen, Met. Eng.

SYNOPSIS

An account is given of the determination of the isothermal transformation diagram for a nickel–chromium die steel, using a recording Leitz dilatometer equipped with a revolving casette. With this device accurate measurements of the elongation as a function of time of the undercooled austenite was made possible. Records of the isothermal transformation diagrams in a form convenient for filing were obtained.

Introduction

In order to draw the isothermal transformation diagram of a steel, the transformation of austenite to ferrite and carbide has to be determined as a function of time. Various methods of investigation are used, namely, dilatometric, microscopic, with X-rays, and by measurement of the magnetic flux, electrical conductivity, and hardness.

One of the most reliable methods is to determine the change in length by a dilatometer, which depends upon the fact that the decomposition of austenite causes an elongation. With mechanical dilatometers the elongation may be read on the dial indicator or the indicator may be filmed at regular intervals.

THE DILATOMETER

In the present investigation a Leitz dilatometer (model *H*) was used ; the operation of this instrument has been described by H. Borchers and H. J. Otto,[1] and by R. N. Gillmor.[2] A standard rod of Cronin and a sample rod are put into quartz tubes, as shown in Fig. 1. The change in length of each rod is transferred through quartz rods to a plate and thence to a prism supported at three points, of which two are moveable and one is fixed. A beam of light falls upon the prism and is reflected on to a sensitive photographic film or paper. If the rods are heated to

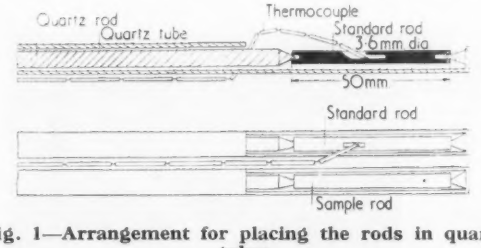

Fig. 1—Arrangement for placing the rods in quartz tubes

850° C. and air-cooled, the horizontal axis will represent the change in length of the Cronin rod, and the vertical axis that of the sample rod, as shown in Fig. 2. As the thermal expansion coefficient of the Cronin rod is known, the horizontal axis also indicates the temperature. The rods are heated at a rate of 3·4° C./min. and cooled in still air to room temperature. It will be seen that a contraction occurs when ferrite is transformed to austenite at 710° C. ; on cooling, the austenite will begin to transform to martensite at 230° C. If the rods are heated to 850° C. and cooled to a temperature below 710° C., and kept at this temperature, the undercooled austenite will transform, the degree of transformation being dependent on time. The luminous point will then describe a straight line parallel to the ordinate and connecting the cooling curve with the heating curve. In this way the elongation can be determined only at the moment the experiment is stopped, but by letting

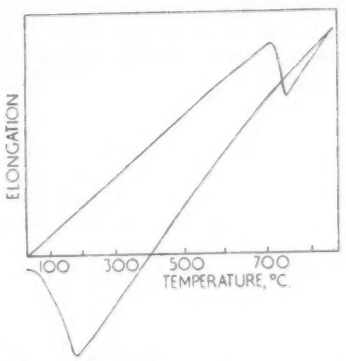

Fig. 2—Dilatometer diagram for a nickel–chromium die steel

the film rotate with constant speed at the holding temperature, the elongation can be obtained as a function of time at constant temperature.

DETAILS OF THE EXPERIMENTS

The steel used for the investigation had the following analysis :

C, %	0·49	Mn, %	0·41
Ni, %	2·97	S, %	0·009
Cr, %	1·87	P, %	0·017
Si, %	0·33		

All the sample rods were annealed at 670° C. for 8 hr. to obtain a uniform structure, all the carbides being spheroidized, and were then turned to a diameter of 3·6 mm. and cut to a length of 50 mm.

Owing to the difference of specific heat between the steel sample rod and the Cronin rod and because of the heat of reaction of the steel rod during transforming, a difference of temperature between the two rods was to be expected. A special test had to be made to determine the magnitude of this difference

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Mr. Andersen is at Stavanger Electro-Staalverk A/S, Jörpeland, Norway.

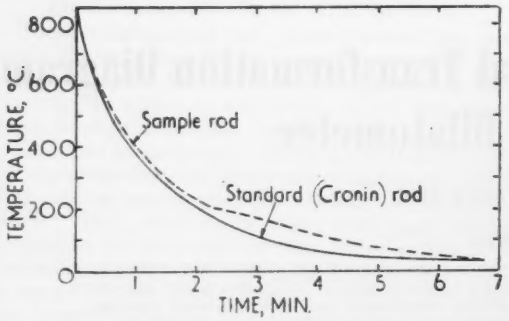

Fig. 3—Cooling curves for sample and standard rods. Air-cooled

and to obtain a basis for correction. To do this, a hole of 1-mm. bore was drilled into the sample rod and into the Cronin rod, and thermocouples were placed into the holes. By observing the fall in temperature during cooling from 850° C., the curves shown in Fig. 3 were drawn. On the basis of the dilatometer diagram (Fig. 2) and the cooling curves (Fig. 3), the corrected diagram shown in Fig. 4 was drawn. This diagram shows the curve as it would have been if both rods had the same temperature during cooling ; the beginning of the martensite formation and its development is shown distinctly.

The experiments were carried out as follows : The rods were placed into the quartz tubes, and the axes were marked by exposing the paper. The starting point of the curve was placed so that the luminous point during the austenite transformation would move along a straight line, the elongation of which

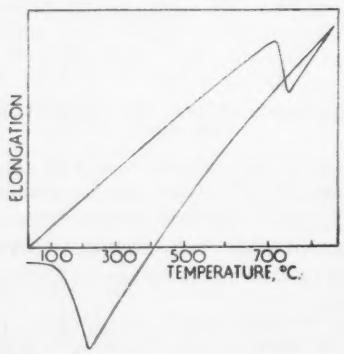

Fig. 4—Corrected dilatometer diagram

would go through the centre of the paper. The rods were placed in a furnace and heated in air at a rate of 3·4° C./min. until the temperature of the rods had reached 850° C. ; as the rate of heating was sufficiently slow, no soaking time was necessary. The rods were then placed in another furnace at the holding temperature. At the same time the revolving casette was set in motion by clockwork. Figures 5 and 6 show the construction of the casette. The photographic paper was made to rotate through a synchronous motor, and by changing the transmission wheels, the number of revolutions per minute of the photographic film could be changed.

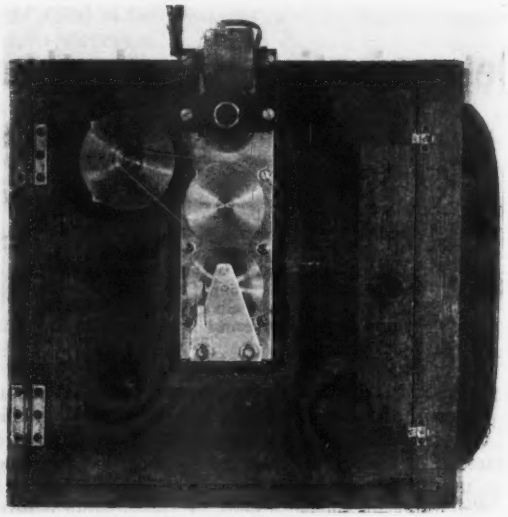

Fig. 5—Rear view of dilatometer casette

From the moment the photographic film was set into rotation, the elongation was registered as a function of time at constant temperature. When the samples had been held at the holding temperature for a sufficiently long time, the clockwork was stopped in the same position in relation to the camera as when it was started. In this way the curves shown in Figs. 7 and 8 were obtained. The general appearance of these curves shows that the transformation rate is slow at the beginning and later accelerates. When the transformation is nearly complete, the rate of transformation is very slow and the spiral will change to circles which overlap each other. To avoid excessive overlapping, the time of each revolution may be increased.

On the basis of 25 isothermal transformation curves the diagram (Fig. 9) was drawn by measuring the time for 5%, 10%, etc., transformation. The percentage of

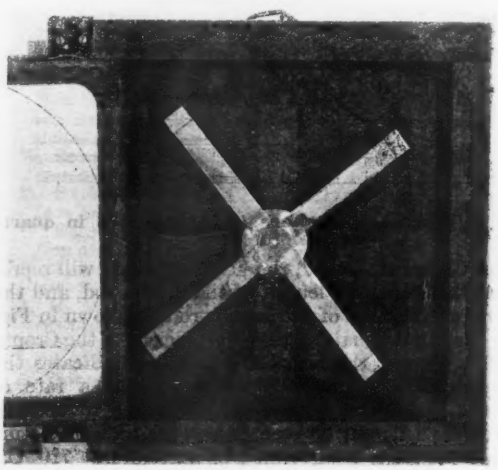

Fig. 6—Front view of dilatometer casette; the circular photographic paper or film is fastened to the cross

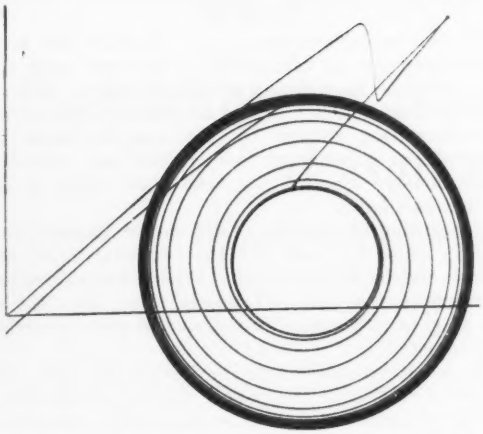

Fig. 7—Transformation curve obtained with a holding temperature of 620–624° C., at 44 revolutions per 4 min. 20 sec.

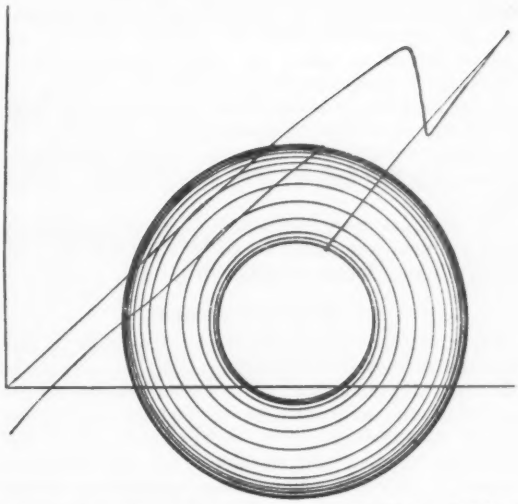

Fig. 8—Transformation curve obtained with a holding temperature of 608–612° C., at 17 revolutions per 4 min. 20 sec.

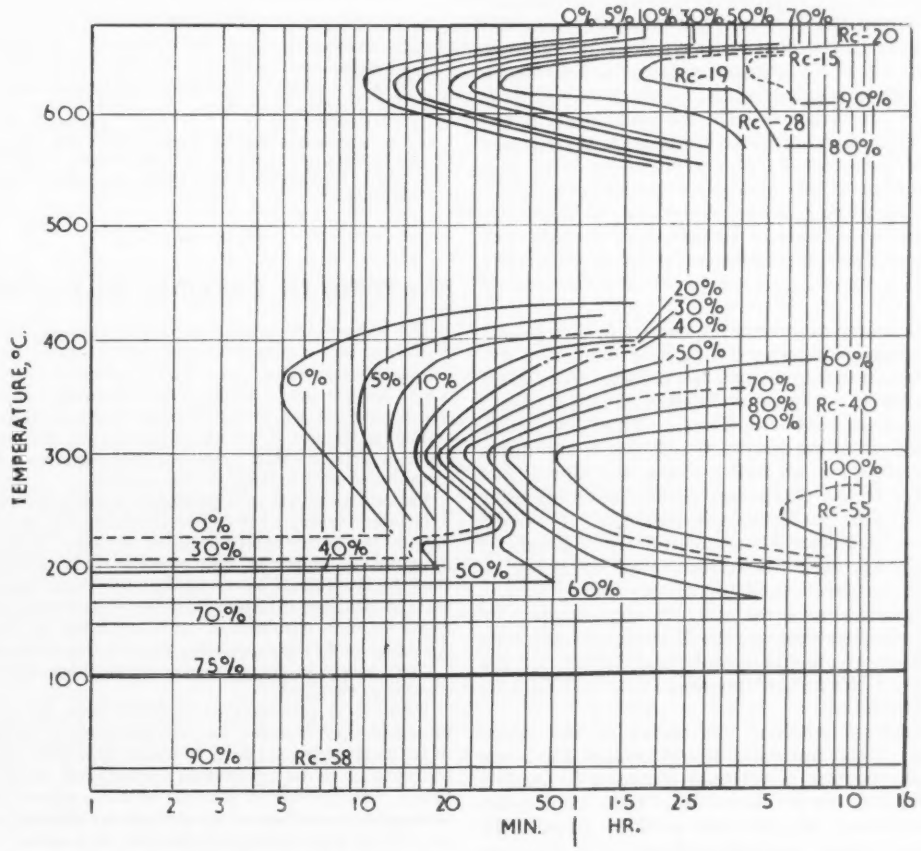

Fig. 9—Isothermal transformation diagram for a nickel–chromium die steel. Grain size No. 8 A.S.T.M., critical (Ac_1) temperature 710° C., austenitizing temperature 850° C., in the annealed condition

transformed austenite is proportional to the elongation, and the distance from the cooling curve to the heating curve is taken as 100% transformation. Below the M_s temperature, martensite transformation is instantaneous; it is therefore unnecessary to take special curves at lower temperatures to determine the martensite transformation, as the degree of transformation can be judged from the normal diagram (Fig. 4).

The samples were examined microscopically and the grain size was found to be No. 8 A.S.T.M., and the maximum decarburization 0·07 mm.

SOURCES OF ERROR

The sources of error discussed relate only to the dilatometric method of determination. Those mostly affecting the accuracy of the isothermal transformation curves are as follows: The austenite grain size affects the shape of the curves; the same is the case with undissolved carbides, as the austenite represents different compositions, according to the quantity of carbides being dissolved. The martensite lines will probably depend only on dissolved carbide.[3,4]

From the dilatometer diagram it may be seen that the cooling curve (Fig. 3) shows a prolonged contraction at 20° C. Whether this is due to retained austenite or to the fact that the distance from the cooling curve to the heating curve does not entirely correspond to 100% transformation, is difficult to decide. (It was not possible to check this microscopically.) In order to make the heating curve entirely accurate, it should always indicate that structure which was stable at the temperature in question. The transformation of the austenite is not necessarily always proportional to the elongation, as austenite precipitates two kinds of phases, *viz.*, carbide and ferrite, and the composition of the formed or the decomposing phases may change during the experiment.

Another source of error is the change in dimensions of the photographic paper during developing and fixing. To estimate this change, two points were marked on the bromide paper at a distance of 20 cm. along and at right-angles to the fibres. After developing and drying, an elongation of 0·4% across the fibres and a contraction of 0·1% along the fibres was measured. If the elongation on the diagram after 0, ½, 1, 1½, etc., revolutions is measured, it will be found that the error is not significant. Readings after ¼, ¾, 1¼, etc., revolutions may at worst be subject to a correction factor of $\frac{99{\cdot}5}{100}$ or $\frac{100{\cdot}5}{100}$, *i.e.*, in the worst case an error of 0·5% may occur.

Transformation errors on the dilatometer have been examined by H. Borchers and H. J. Otto.[1] In the present work the highest possible error will be 0·2–0·3% 'absolute.'

To determine whether the course of the transformation of the austenite would remain the same under faster cooling, a salt bath was used for cooling to the holding temperature. The rods were taken from the furnace into the salt bath by tipping the dilatometer, which took 1½ to 2 sec. For the steel examined, the course of the transformation of the austenite remained the same whether cooling took place in a salt bath or in air.

SUMMARY

An isothermal transformation diagram has been determined for an oil-hardening die steel, and the data obtained have shown good conformity. With a suitable time of revolution for the photographic paper, the elongation caused by the transformation of austenite at a constant temperature was indicated continuously. Cooling can take place either in air or in a salt bath.

Concerning the ordinary dilatometer diagram, correction must be made for the temperature of the sample rod by cooling in air. When this is done the dilatometer diagram will clearly show the time of the start of martensite formation and also its further development.

At most, a relative error is possible of 0·5%, due to the shrinking of the paper. Transferential errors on the dilatometer amount to 0·2–0·3% 'absolute.'

Acknowledgments

The author wishes to express his thanks to Stavanger Electro-Staalverk A/S and to the Technical Director, who initiated and supported this work. Thanks are also due for permission to publish the results.

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BLASTING OF CASTINGS IN FACTORIES

The risk of contracting silicosis in the case of persons employed in, or in connection with, blasting is still a matter of serious concern. The blasting in question has been defined as meaning the cleaning, smoothing, roughening, or removing of part of the surface of any article by the use, as an abrasive, of a jet of sand, metal shot, or grit or other material, propelled by a blast of compressed air or steam, or by a wheel.

Various measures and precautions have been adopted in industry with a view to reducing the risk, and to some extent these are already required by law. In the light, however, of enquiries and experience it is considered that the law should be strengthened by new regulations; and the Minister of Labour and National Service proposes to make such regulations, to be entitled the Blastings (Castings and Other Articles) Special Regulations, 1949.

The objects of the proposed regulations are, broadly speaking, two-fold.

First, it is proposed to prohibit what is commonly known as sand-blasting, *i.e.*, the use of siliceous abrasives in blasting apparatus with, however, a provision enabling exemptions to be granted in exceptional cases, if it is found that the use of sand or of some other substance containing free silica as an abrasive in blasting is necessary for a particular manufacture or process.

Secondly, the proposed regulations would prescribe more elaborate precautions than are at present legally required in connection with blasting in, or incidental to, the cleaning of castings.

Experiences in the Study of Isothermal Transformations

By T. F. Russell, F.I.M. and C. Mavrocordatos, B.Met.

SYNOPSIS

Part I describes an apparatus for exploratory work on isothermal transformations of slowly reacting steels by the magnetic method. Self-recorded diagrams showing temperature and magnetic change in transformations requiring hundreds of hours have been obtained. The apparatus revealed, many years ago, the remarkable stability of the austenites of some steels at temperatures between the pearlite range and the intermediate range, and the stability of partial transformation in the latter range. The apparatus also has limitations. It is shown, for example, that the austenite of a 3% chromium steel may change completely to pearlite in the non-magnetic condition.

In Part II the coefficients of thermal contraction of a number of austenites down to temperatures near the M_s points are given, and the change of length of the specimen during isothermal transformation is recorded for a number of hypo- and hyper-eutectoid steels. The predominating effect of carbon on these changes of length is discussed, and the relation of the final length to that of an aggregate of ferrite and carbide is shown.

Introduction

BEFORE the publication by Davenport and Bain,[1] in 1930, of their classical paper on the transformation of austenite at constant sub-critical temperatures, the most commonly used method of studying phase changes was to plot inverse-rate curves from time/temperature data obtained during the heating and cooling of steel. This is still one of the best methods for determining the change points on heating, as these temperatures are practically independent of the rate of heating. During the cooling of steels, however, the reactions may be so complex, and the form of the curves vary so much with the rate of cooling, that it is, as already shown by one of the authors,[2] almost an impossibility always to interpret the curves correctly without previous knowledge not only of the heat changes accompanying a phase change, but also of the rate at which the reactions proceed at each temperature. The writers' opinion of time/temperature data, no matter how plotted, as a method of studying phase changes during the cooling of steel, may be summed up by saying that the method has been almost completely abandoned in the authors' laboratory during the last ten years. On the other hand, work on the isothermal transformation of steels started shortly after the publication of Davenport and Bain's paper, and has gone on continuously ever since.

The first steels to be investigated were the nickel–chromium and nickel–chromium–molybdenum structural steels, which were being produced in large quantities as bars and forgings. It was known that some of these steels required very long times (up to 100 hr. or more) for transformation to take place in the pearlite* range. The dilatation method described in Part II, requiring constant watching and recording of dial and time readings, did not appear to be suitable for studying these reactions, and some continuous self-recording method seemed essential. The magnetic method described in Part I was chosen, as, at that time, it was thought that the decomposition of austenite was invariably accompanied by a change in magnetic induction ; an important exception to this rule will be referred to later.

PART I—THE MAGNETIC METHOD

After a few preliminary experiments the relatively simple apparatus shown in Fig. 1 was devised.

The apparatus consists of two exactly similar copper water jackets, each wound with the same number of turns (about 1250) of copper wire. The two primary windings thus formed are connected in series to the double-pole, double-throw switch (No. 1), which enables either A.C. or D.C. to be passed through them. Two secondary windings, each consisting of 100 turns of copper wire, are connected in series-opposition to the D.P./D.T. switch (No. 2). This switch connects the secondary windings either to a ballistic galvanometer circuit, or, through a suitable resistance, to a metal instrument rectifier, the output of which passes through the variable resistance R. The potential difference across R is applied to one point of a two-point potentiometric recorder, the other point of which records simultaneously the temperature of the specimen. The rectifier is kept at constant temperature in a thermos flask, since its characteristics vary appreciably with temperature. The specimen, 3 in. long × ½ in. dia., with a hole drilled to the centre to take a thermocouple, is heated in an evacuated refractory tube by means of a small non-inductively wound furnace inside one of the water jackets.

With no ferromagnetic material present in the furnace, the output from the secondaries, when A.C. is passed, or D.C. reversed through the primaries, is zero. When ferromagnetic material is present, the

* In this paper, the terms " pearlitic product " and " pearlite " are used in their widest sense for all products of the transformation of austenite in the pearlite range of temperature, irrespective of their structural features.

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Mr. Russell is Senior Metallurgist, and Mr. Mavrocordatos, Assistant Metallurgist, at the English Steel Corporation, Sheffield.

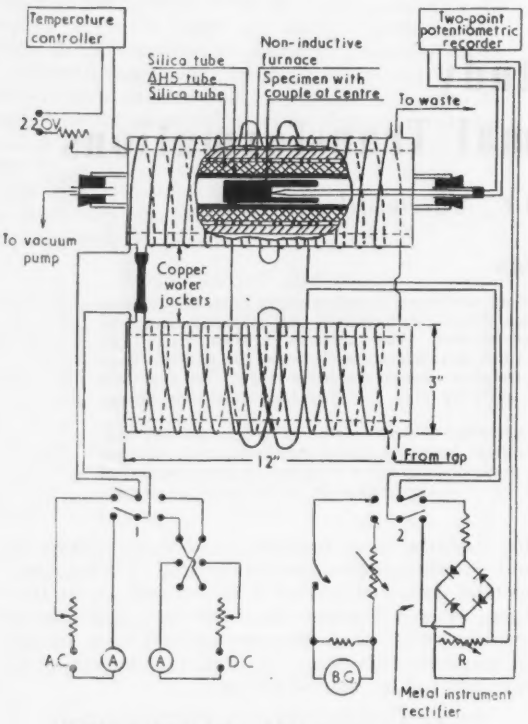

Fig. 1—Thermal-magnetic apparatus

increase in magnetic flux embraced by one secondary gives either a throw on the ballistic galvanometer for D.C., or a reading on the recorder for A.C. operation. These readings are used as an indication of the amount of ferromagnetic material present, and serve as a means of following the transformation of a specimen from the austenitic (*i.e.*, non-magnetic) form to a ferromagnetic product.

Experience has shown that this apparatus has definite limitations for the study, with academic accuracy, of isothermal transformation curves. Nevertheless, it is exceedingly useful in helping to obtain a broad picture of the behaviour of a large number of steels which react slowly. It has brought to light certain phenomena which could not possibly have been predicted from the original work. Some of these will be dealt with under separate headings.

THE PEARLITE RANGE

In the first experiments the heatings and coolings were not done in a vacuum, and a new test-piece was used for each experiment. The times for the beginnings and ends of reaction, even after allowing for the difficulty of reading these figures from long lengths of recorder chart, gave so much scatter, when plotted in the usual manner as isothermal transformation curves, that a satisfactory curve could not be drawn through them. It was suspected that the small amount of scale formed on the test-pieces was having some effect, but no better results were obtained on repeating the experiments with the furnace tube evacuated. It was found, however, that if the same test-piece was used for a whole series of experiments, duplicate tests gave results in good agreement with one another, and satisfactory isothermal transformation curves could be drawn.

A selection of curves is shown in the top half of Fig. 2. Time is given on a linear scale, as this shows up the difference better than a logarithmic scale. The full, dashed, and dot and dashed lines are for three different test-pieces, and it is obvious that satisfactory curves, indicating beginnings and ends of reaction at different temperatures and truly representative of the steel, cannot be drawn. From the isothermal transformation curves it is equally obvious that the differences in the magnetic induction/time curves taken at 637° and 639°, or at 654° and 657°, are not caused by temperature differences and, as the order of magnitude of the differences is much greater than would be caused by slight differences in the austenitizing temperature or time of soaking, the only inference is that different test-pieces may vary appreciably in the intensity of nucleating factors. This is probably more or less true for all steels, but is well brought out in very slow-reacting steels. It was noticed that, for this steel and for all others tested since (both by the magnetic method and by the dilatation method), the temperature at which the austenite transforms most readily in the pearlite range is a constant for each steel, and depends only on the chemical composition of the steel; the actual rate at that temperature depends on a number of factors. The points on the bottom half of Fig. 2, marked *NS* or *NF*, show temperature and time of test, and indicate that the change in magnetic induction had either not started or had not finished at the end of that time; the position of the points marked *NS* (100 hr.) shows the temperature at which the tests were made.

Similar 100-hr. tests made at progressively lower temperatures revealed the remarkable stability of the austenite of this steel between about 600° C. and 490° C., since in no test in this range of temperature was there the slightest indication of any change from non-magnetic to ferromagnetic material.

THE INTERMEDIATE RANGE

At temperatures in the range of about 490° to 400° C. some transformation of austenite took place.

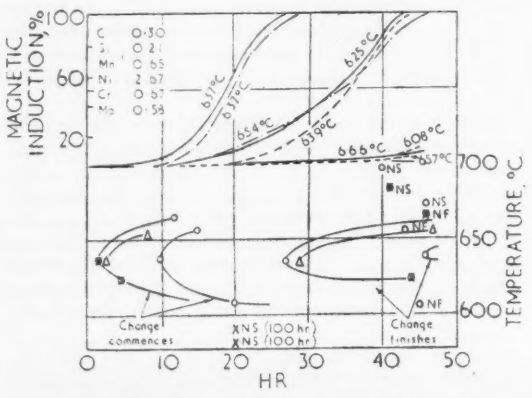

Fig. 2—Transformation in the pearlite range

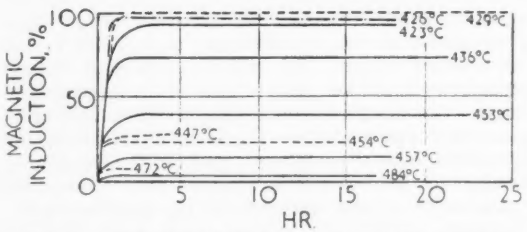

Fig. 3—Transformation in the intermediate range

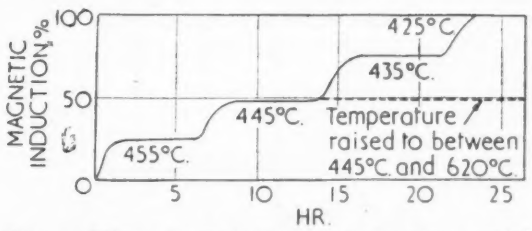

Fig. 4—Effect of varying temperature after partial isothermal transformation, shown schematically

but the kinetics of the reaction in this range of temperature were totally different from those in the pearlite range. Reaction set in much earlier, and the magnetic induction reached what was then thought to be an equilibrium value of the partial transformation of non-magnetic to ferromagnetic material. Figure 3 shows the results of ten tests, using three test-pieces in this range of temperature, and it will be seen that there was less difference in the behaviour of different test-pieces than there was in the pearlite range, and that at each temperature equilibrium had apparently been reached. The effect of altering the temperature during a test is shown diagrammatically in Fig. 4. If the partial transformation of austenite is allowed to take place at one temperature and the temperature is successively lowered, further transformation sets in and reaches a value characteristic of the new temperature. This phenomenon repeats itself until the temperature is lowered to 423° C., when transformation is complete. If, however, during the course of a test, the temperature of holding is raised, the amount of magnetic induction is unaltered. If the temperature is raised into the stable region above 490° C. there is no further decomposition of the austenite, and for a slowly reacting steel, such as the one under consideration, the temperature may even be raised into the pearlite region, for times comparable with those used for commercial tempering, without further decomposition of the remaining austenite. The practical importance of this is well demonstrated by the following test.

Two bars, *A* and *B*, of the composition shown in Fig. 2, were soaked at 850° C. for 4 hr. The bar *A* was transferred to a salt bath standing at 450° C. and the bar *B*, to a salt bath at 395° C. for a period of 2 hr. The transformation should have been completed in *B*, but only partially completed in *A*. Both were immediately tempered for 4 hr. at 650° C. and then air-cooled. The mechanical test results were :

	Tons sq. in.				Reduction	
	0·05% Proof Stress	0·2% Proof Stress	Maximum Stress	Elong. on 2 in., %	in Area on $4\sqrt{A}$, %	Izod Impact, ft.-lb.
A	24·6	39·9	82·5	10·2	15·0	6, 7, 6
B	41·7	43·7	59·6	20·8	51·4	35, 42, 36

The difference in these mechanical properties is due entirely to the presence in piece *A* of some untempered intermediate product, which was formed by the decomposition of the residual austenite on air-cooling from the tempering temperature.

There was, and indeed still is, considerable speculation on the cause of the transformation characteristics in the intermediate range of temperature of steels of this type. The change is an irreversible one, and is promoted by lowering the temperature. In these two respects, at least, the change is analogous to the austenite to martensite change. Any theories based on the concepts of there being two or more phases in true equilibrium, or of transformation being suppressed by the building up of internal pressure, or the partial transformations being connected with the gradients of chemical composition in the dendritic structure of the austenite grains, will have to be abandoned. From the known behaviour of the less sluggishly reacting steels and from the known behaviour of austenite at temperatures below the M_s point, one is inevitably led to the conclusion that the austenite will completely decompose at all temperatures below the A_e point if held at temperature long enough.

THE CHANGE FROM AUSTENITE TO PEARLITE IN THE NON-MAGNETIC CONDITION

In one of the early experiments on the isothermal transformation of a 3% chromium–molybdenum steel after austenitizing at 900° C., it was found that at temperatures around 766° C. the thermal magnetic apparatus apparently went awry, although it behaved normally at lower temperatures. The potentiometric-recorder diagrams gave no clue to the cause of the erratic behaviour, but, by very frequent measurements of the magnetic induction by the ballistic method, it was found that the amount of magnetic induction was varying cyclically with a periodicity exactly coinciding with a narrow range of temperature oscillations caused by the temperature controller ; the magnetic induction increased as the temperature fell and *vice versa*. The appreciable change in the amount of magnetic induction was therefore taking place over a very narrow range of temperature, about 2° C., and was strictly reversible, as it responded immediately to temperature changes. The latter phenomenon disposed of any suggestion that the magnetic change was caused by alternating austenite → pearlite → austenite changes, or to alternating precipitation and re-solution, in the macro sense, of precipitated ferrite. Here was something new, as far as the then known behaviour of chromium steels on cooling from the austenitic condition was concerned, and obviously called for a full investigation.

The interpretation of the results of the few experiments to be described will be better understood if what happens during the continuous heating and cooling of this class of steel is first recalled. It has been known for more than half a century that the

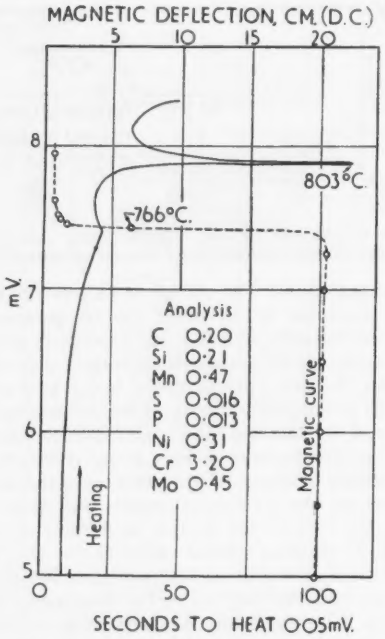

Fig. 5—Inverse-rate and magnetic induction curves for 3% Cr–Mo steel

addition of chromium to a carbon steel raises the temperature of the carbide change point, Ac_1, and Moore[3] showed in 1910 that the Ac_1 point could be raised to a temperature above the magnetic change point Ac_2. As the steel used contained 0·31% of nickel and 0·45% of molybdenum, the relative displacements of the Ac_1 and Ac_2 points were confirmed by taking simultaneously an inverse-rate heating curve and magnetic induction/temperature curve. These curves are given in Fig. 5 and show that such quantities of nickel and molybdenum have no effect on these types of curves for a 3% chromium steel.

It is also a well known fact that when these high chromium steels are cooled from the austenitic state at the slowest rate at which it is convenient and practicable to take an inverse-rate cooling curve, the transformation of austenite, with its evolution of heat and magnetic change, takes place at some temperature, or range of temperature, below Ac_2. The reason is, of course, that at temperatures between A_e and that of the magnetic change the rate of transformation of austenite, and therefore the rate of evolution of heat, is so slow that it is impossible to detect it by thermal methods.

The highest temperature at which the Ar_1 change can be detected by inverse-rate plotting has its peak at 730° C. On successively increasing the rate of cooling from the austenitizing temperature the usual phenomena are observed, *viz.* : the austenite may transform completely in the pearlite range, and the temperature at which transformation takes place most rapidly, as indicated by the peak on the inverse-rate curve, is depressed as the rate of cooling is increased ; at faster rates of cooling, the transformation takes place partly in the pearlite range and partly in the intermediate range ; with still faster rates of cooling, transformation takes place wholly in the intermediate range. The change from austenite to martensite takes place only if pieces of very thin sections are drastically quenched, and for the present purpose the change can be ignored. Depressing the temperatures of austenitic transformation also carries down the magnetic transformation, and at all temperatures below the Ac_2 point any transformations of the austenite can be detected from the resulting changes of the magnetic induction. On the other hand, if the transformations on heating, as depicted in Fig. 5, were more or less reversible it should be possible to transform the austenite completely to a pearlitic product at some temperatures above the Ac_2 temperature ; that is, the transformation would take place in the non-magnetic condition, and the magnetic change would take place when the temperature was lowered to the Ac_2 temperature. If the time of holding at a temperature between A_e and Ac_2 is not long enough to allow complete transformation of the austenite, the untransformed austenite becomes richer in carbon than the original austenite, and one might expect this residual austenite to behave, on continuous cooling, in the same way as an homogeneous austenite of the same carbon content on cooling from above the Ac_1 temperature ; the effect of the increased carbon content would be to lower the temperature at which transformation recommences. Both these predictions have been confirmed by experiment.

The composition of the steel used was approximately : C 0·20%, Si 0·21%, Mn 0·47%, Ni 0·31%, Cr 3·20%, Mo 0·45%. The peak on the inverse-rate heating curve is at 803° C. The A_c point is probably 5° or so lower than this, and at the A_c temperature an infinitely long time would be required for complete transformation. The times required become shorter as the temperature is lowered, but preliminary tests showed that it would be necessary

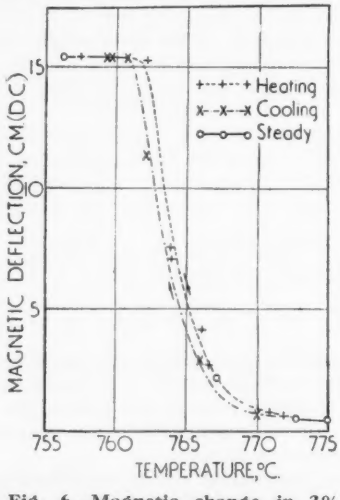

Fig. 6—Magnetic change in 3% Cr–Mo steel in the pearlitic condition throughout

to transform isothermally at a temperature as near as possible to the beginning of the magnetic change, if it was hoped to complete the transformation in a reasonable time.

The range of temperature of the magnetic change was determined by repeated heatings and coolings over the range 750–775° C. The results are given in Fig. 6, and show that the range is approximately 761–772° C., and that there is less than 1° C. temperature lag, if any, on heating and cooling. The range is independent of the rate of heating and cooling.

Four isothermal transformation experiments were therefore made at 772° C. in the magnetic testing apparatus. In each experiment, a small disc specimen, $\frac{1}{8}$ in. × $\frac{1}{2}$ in. dia., was placed touching the larger, 3 in. × $\frac{1}{2}$ in. dia., specimen. The specimens were heated *in vacuo* to 900° C. and held for 30 min. The temperature was then lowered to 772° C., and the times of holding in the four tests were 7 min., 5 hr., 7 hr., and 70 hr. At the end of these times the small specimen was quickly removed, quenched in 10% NaOH solution, tested for hardness, examined microscopically, and the amount of transformation at 772° C. estimated. After removal of the micro-specimen the heating current was switched off and the larger specimen was cooled at the natural cooling rate of the furnace. Meanwhile the temperature, time, and magnetic changes were being autographically recorded down to about 300° C. The results are summarized in Fig. 7, which gives the magnetic induction/temperature curves. When the usual 3 in. × $\frac{1}{2}$ in. dia. specimen is cooled from 900° C. at the natural rate of this furnace the pearlitic change is completely suppressed ; all the change takes place in the intermediate range, and the change from the non-magnetic to magnetic condition takes place simultaneously. The interpretation of the curves shown in Fig. 7 must, therefore, be as follows.

The temperature of the tests, *viz.*, 772° C., is just about the upper limit of the Ac_2 range, and the very small constant amount of induced magnetism, even after holding for 70 hr., was no more than would be expected from the results shown in Fig. 6.

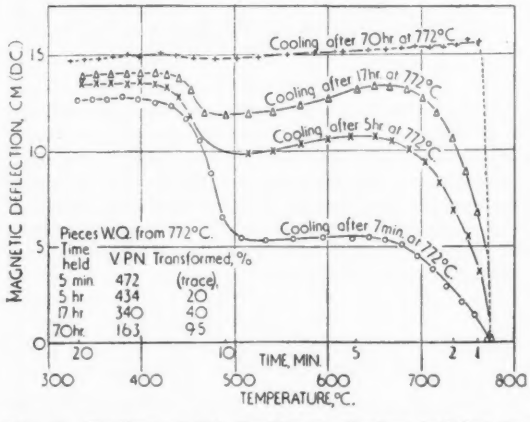

Fig. 7—Cooling of 3% Cr–Mo steel after holding for various times at 772° C. Maximum temperature 900° C. for 15 min.

After holding for 7 min. at temperature the micro-section of the quenched specimen showed that very small quantities of ferrite had separated out, and the V.P.N. hardness was 472. An increase in the magnetic induction was recorded immediately the larger specimen started to cool, and took place in two distinct stages. The first, or austenite → pearlite stage, probably accelerated by the nuclei of ferrite, ceases at about 650° C., to be followed by a period of relative stability of the austenite down to about 510° C., when transformation of the remaining austenite to intermediate product begins.

When the test-pieces were held for 5 hr. and 17 hr. at 772° C., micro-examination showed that approximately 20% and 40% of the austenite had been transformed, and the hardnesses of the quenched specimens were 434 and 340 V.P.N. respectively. On cooling the larger pieces it is probable that the ferritic constituent of the pearlitic product of decomposition at 772° C. first becomes magnetic, and is followed or overlapped, by a further increase of magnetism, owing to more of the austenite decomposing in the pearlite range. Then comes the period of relative stability and the final decomposition of the residual austenite below 500° C.

The microstructure of the specimen held for 70 hr. and then quenched showed principally ferrite and coalesced carbide, with about 5% of what appeared to be martensite. The hardness was 163 V.P.N. This 5% of untransformed material may be a stable phase at 772° C., in some way connected with the presence of molybdenum, for it is now believed that the 95% transformation would take place in less than 70 hr. and it must be remembered that the change from austenite to pearlite was taking place without the slightest indication on the magnetic induction curve. The magnetic change was practically completed after cooling the larger specimen some 10 to 12° C., except for a small but distinct change at about 440° C.

In some earlier experiments the steel was heated for 30 min. at 900° C., cooled to 776 ± 1° C., *i.e.*, about 4° C. above the upper limit of the range of magnetic transformation, held for 5 min., and then cooled in the apparatus with the heating current off ; the magnetic induction/temperature curve is shown in Fig. 8, together with that of another specimen held for 17 hr. at the same temperature. These curves show that, on cooling and holding for only 5 min. at 776° C., a small quantity of ferrite must have been precipitated, and microscopic examination of the specimen held for 17 hr. showed the presence of about 20% of free ferrite which had been precipitated without any indication of a magnetic change.

In another test, the specimen was held for 77 hr. at 776° C. and over the next 65 hr. the temperature fell to 770° C. At the latter temperature the small but distinct amount of magnetic induction recorded was again about the same as would be expected from the curve in Fig. 6. The furnace was now very slowly cooled with the temperature controller still on, and therefore its temperature was oscillating ±1° C. about its mean value. Cooling from 770 to 780° C. took about 8 hr. As the steel cooled its magnetism increased, until it reached its full value at about

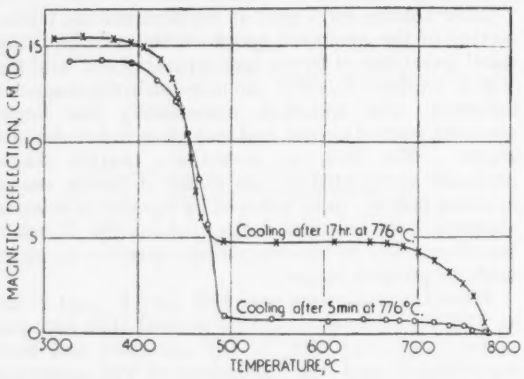

Fig. 8—Cooling of 3% Cr–Mo steel after holding for various times at 776° C. Maximum temperature 900° C. for 30 min.

760° C., but as the temperature was undergoing cyclic changes, so did the magnetic induction, by amplitudes closely in agreement with those to be expected from Fig. 6 ; *e.g.* the change in the reading for a 2° C. change of temperature was a maximum at 764 to 762° C.

These experiments, and others, confirm that : (i) the almost strictly reversible magnetic change, Ac_2, takes place over the temperature range 772–761° C. in the steel used, if it consists of ferrite and carbide at the time, (ii) transformation of austenite at all temperatures *below* 761° C. is accompanied by a magnetic change which is not reversible, and (iii) transformation of austenite at temperatures *above* 772° C. and below the A_c temperature takes place in the non-magnetic condition. As Figs. 7 and 8 show, when partial transformation takes place in the pearlite range, the temperature at which the residual austenite begins to transform is lowered as the amount of transformation in the pearlite range increases. This is in conformity with the generally accepted view that as the transformation in the pearlite range progresses the residual austenite becomes richer in carbon.

PART II—THE DILATATION METHOD

Most of the work at the English Steel Corporation on isothermal transformations is now done by the dilatometric method, the apparatus being very similar to that described by Allen, Pfeil and Griffiths.[4]

The dilatation method has several advantages over the magnetic method. If the changes in length with time and temperature are accurately measured it should be possible to estimate not only the coefficient of contraction of austenite at sub-critical temperatures, but also the percentage change in length during transformation. There is still some doubt whether it is strictly correct to calculate the change in volume from the change in length, but the former can surely be calculated approximately from the latter. A knowledge of the volume changes which take place when a steel is transformed is essential for the calculation of stresses set up during the cooling of steel. Another advantage of the method is that it should, theoretically, be possible to detect the beginning of precipitation of pro-eutectoid ferrite or pro-eutectoid carbides, the precipitation of ferrite causing an expansion, and the precipitation of carbides causing a contraction.

In practice, however, none of these things is easily measured, and indeed, in an apparatus which consists of one silica tube sliding over another in a bath of molten metal it would be surprising if accurate results were always obtained. Nevertheless, by examining a large number of results, any well-defined tendencies should be brought into prominence.

Rather more accurate and consistent length measurements have recently been obtained by using a test-specimen of the form shown in Fig. 9, instead of the usual conical-ended specimen. The inner silica tube now sits firmly on the flat top of the test-specimen, and the hemispherical lower end gives better contact with the lower end of the outer tube. The length AB is carefully measured, and the effective length AC is calculated.

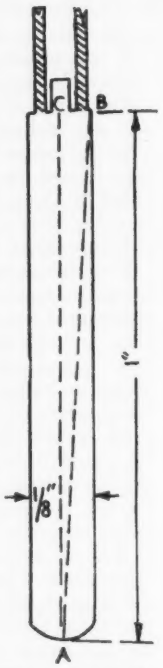

Fig. 9 — Longitudinal section of test specimen

The general comments on length change given in the next two sections arise from a recent re-examination of dilatation curves taken during the ordinary course of work on isothermal transformations, where austenitizing temperature, bath temperature, and time are the three most important variables. The results do not arise from a special research—were that the case a better selection of steels would have been made.

The analyses, temperatures of Ac_1, M_s, and the austenitizing temperature of all steels referred to are given in Table I.

THE COEFFICIENTS OF THERMAL CONTRACTION OF AUSTENITES

The average coefficient of contraction was determined from the original length, and the dial readings at atmospheric temperature, at the austenitizing temperature, and when the specimen reached the bath temperature some 20 to 25 sec. later. The range of temperature thus varied for any one steel from the austenitizing temperature to a lower limit anywhere between the Ac_1 and M_s points. The coefficients were calculated from the formula :

$$\alpha = \frac{L - l}{lT - Lt},$$

where L = length at the austenitizing temperature T, and l = length at the bath temperature t.

That is to say, the coefficients assume the hypothetical length at 0° C. to be unity. They are relative to silica, and should be increased by $0{\cdot}5 \times 10^{-6}$ for absolute values.

Table I

COMPOSITION AND OTHER RELEVANT DATA OF STEELS EXAMINED

Steel	Analysis						Other Elements	M_s, °C.	Ac_1, °C.	Austenitizing Temp. °C.
	C, %	Si, %	Mn, %	Ni, %	Cr, %	Mo, %				
A	0·26	0·21	0·55	0·25	3·30	0·54		350	805	900
B	0·31	0·20	0·62	2·63	0·64	0·58		320	730	835
C	0·38	0·20	0·69	1·58	0·95	0·26		315	735	835
D	0·38	0·18	0·53	1·53	1·40	0·32		310	750	850
E	0·39	0·25	0·71	0·56	1·09	0·42		315	745	850
F	0·39	0·23	0·62	1·44	1·11	0·18		320	738	850
G	0·39	0·28	1·52	0·10	0·68	0·44		305	735	850
H	0·42	0·31	0·67	2·53	0·72	0·48		265	732	830
J	0·15	0·25	0·41	3·02	0·90	0·15		400	720	900
K	0·90	0·25	0·41	3·02	0·90	0·15		210	720	900
L	0·72	0·35	0·92	0·50	0·12	0·25		226	725	850
M	0·80	0·32	1·32	0·55	0·07	0·21		170	720	850
N	0·85	0·29	0·97	0·20	1·00	0·42	V, % 0·11	160	754	900
P	0·95	0·28	0·25	0·14	1·61	0·04		200	750	900
Q	0·69	0·33	0·80	0·46	1·15	0·29		220	754	850
R	0·72	0·32	0·85	2·50	1·09	0·46		215	n.d.	900
S	0·90	0·27	0·58	0·16	1·85	...	W, % 1·20	235	760	850
						...		125	760	950
						...		125	760	1050

In Table II the results from 153 tests on 12 different steels are summarized. An examination of the results for any one steel shows that there is no tendency for the average coefficient of contraction to decrease or increase as the range of temperature over which it is measured, from the austenitizing temperature downwards, is increased. This would be the condition if the true contraction curve were concave upwards or downwards respectively, and the writers believe that the coefficients of contraction of the austenites are independent of temperature when cooling is so rapid (in this work about 2000° C. per minute) that all traces of phase change are suppressed.

VOLUME CHANGES DURING THE TRANSFORMATION OF AUSTENITE

The dilatation curves obtained when a steel is transforming at constant temperatures in the pearlite range can be divided into three types, as shown in Fig. 10. Curves of the types shown in (*a*) and (*c*) are obtained when the steel and the temperature of test are such that there is a relatively large precipitation of pro-eutectoid ferrite or carbide before the change from austenite to pearlite. There is no sharp division between types (*a*) and (*b*), or between (*b*) and (*c*), with the result that most of the curves obtained during the course of work on isothermal transformation are of type (*b*). They are given by eutectoid steels at all temperatures of test above the M_s point, provided the transformation of austenite is completed, and by both hypo- and hyper-eutectoid steels when the temperature of test is such that there is either no precipitation of pro-eutectoid ferrite or carbide. They are also found when there is precipitation, as proved by microscopic examination, but in such amounts that the dilatation curve could not, by visual examination, be called type (*a*) or (*c*). In these cases an attempt was made to divide the curve into two portions, as will be described later.

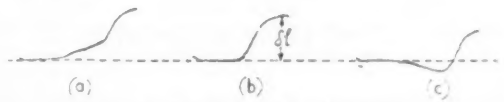

Fig. 10—Types of dilatation curve

The increase in length, δl, at 100% transformation of 12 steels, all of which gave dilatation curves approximating to type (*b*), was measured and expressed as a fraction of the length of the test-piece at the temperature of test before transformation set in.

The lower carbon series are all hypo-eutectoid steels, so that, as confirmed by microscopic examination, there was precipitation of some primary ferrite when isothermal transformation took place at the higher temperatures, and in some cases there was a distinct suspicion of a departure of the dilatation curve from type (*b*) towards type (*a*). All the dilatation curves obtained in the higher temperature regions were

Table II

COEFFICIENT OF CONTRACTION OF AUSTENITE RELATIVE TO SILICA, × 10^6

Steel	Average	Highest	Lowest	No. of Tests
A	21·7	23·0	20·1	11
B	22·4	24·4	20·5	25
C	21·9	22·8	21·2	9
F	22·3	23·9	20·3	10
G	21·1	23·2	19·3	14
H	22·0	22·9	20·9	13
J	21·4	22·6	20·7	6
K	21·5	22·5	20·6	18
N	21·0	22·3	19·6	18
P	21·3	22·9	19·9	13
Q	21·2	22·0	20·2	7
R	21·3	22·4	19·5	9

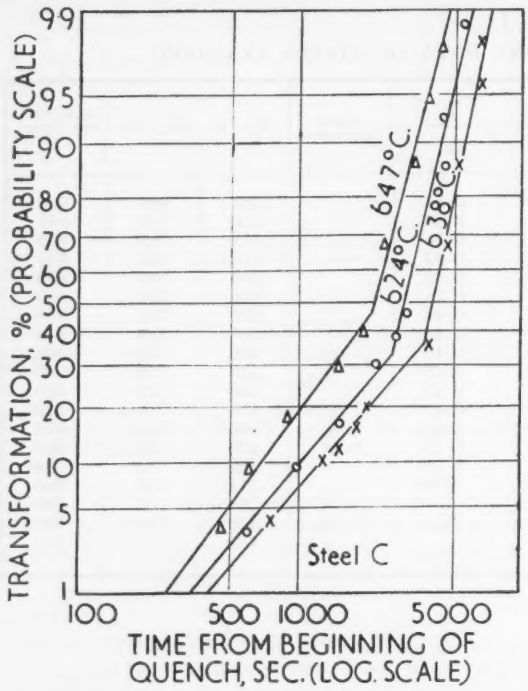

Fig. 11—Dilatation curves plotted on probability/log. time scales

re-examined by plotting the expansion, expressed as a fraction of the total expansion, on a probability scale against time on a logarithmic scale ; any abrupt change in direction of such a plot indicates a change in the law governing the progress of the reaction. In some cases, as shown for example in Fig. 11, two good straight lines were obtained, and it has been tentatively assumed that the point of intersection of these lines indicates the relative amounts of expansion caused by the precipitation of primary ferrite and the decomposition of the residual austenite.

The four higher carbon steels are about eutectoid or hyper-eutectoid composition. When transformed isothermally at the higher temperatures some of the steels showed precipitation of excess carbide, but all the dilatation curves appeared to be of type (*b*). They were re-plotted on probability/logarithmic time scales but gave no definite indication of discontinuity. The most likely explanation is that equal differences in carbon content on either side of the eutectoid composition would produce very much more free ferrite in hypo-eutectoid steels than free carbides in hyper-eutectoid steels.

All the results for the hypo-eutectoid steels, including the tentative division of the expansion into that caused by the precipitation of pro-eutectoid ferrite and that caused by the decomposition of the residual austenite, are given in Table III. The results for the hyper-eutectoid steels are given in Table IV.

In Fig. 12 the expansions for each steel are plotted against the temperature of isothermal transformation, each curve having the Ac_1 and M_s temperatures marked by short vertical lines. The best straight lines have been drawn through the points for the hypo-eutectoid steels, and curves have been drawn through the others. This may give the impression

Table III

EXPANSION DATA—LOWER CARBON STEELS

Steel	Bath Temp., °C.	$\frac{Ac_1 - B_t}{Ac_1 - M_s}$	Expansion, in./in. × 10^4		
			Ferrite	Pearlite	Total
A	740	0·143	...	31	31
	670	0·297	...	35·6	35·6
	634	0·376	...	36·4	36·4
B	638	0·224	14·5	18·5	33
	634	0·234	16	18	34
	624	0·259	17	17·2	34·2
	360	0·902	...	...	56·8
	325	0·988	...	...	65
C	647	0·210	15	17·1	32·1
	644	0·217	11	20	31
	638	0·231	14·6	19·2	33·8
	624	0·264	13	19	32
	603	0·314	6	29·4	35·4
	418	0·755	...	...	55
	361	0·890	...	...	57
	320	0·988	...	...	65
D	692	0·132	4·6	24·4	29
	650	0·227	3	26	29
	617	0·302	2·5	29·5	32
	578	0·391	...	...	36
	562	0·427	...	...	38
	388	0·823	...	...	52
	358	0·891	...	...	55
	327	0·961	...	...	60
E	696	0·114	n.s.	n.s.	27
	670	0·174	,,	,,	29
	639	0·247	,,	,,	32
	631	0·265	,,	,,	30·5
	617	0·298	,,	,,	34
	603	0·330	,,	,,	35
	588	0·365	,,	,,	37
	362	0·891	...	...	56·5
F	670	0·161	14·4	15·6	30
	634	0·246	10·5	23	33·5
	600	0·326	6·3	28·7	35
	420	0·752	...	...	53
	360	0·894	...	...	57
G	625	0·256	n.s.	n.s.	31
	614	0·281	,,	,,	34·3
	614	0·281	,,	,,	35
	378	0·830	...	...	56
	346	0·905	...	...	60
H	663	0·149	...	30	30
	623	0·236	...	31	31
	320	0·892	...	...	55·2
	302	0·931	...	...	60

The letters n.s. denote that the division of the total expansion was not satisfactory

that there is a fundamental difference in the behaviour of hypo- and hyper-eutectoid steels, but the authors do not subscribe to this view, and it is believed that more accurate work will ultimately show that all the curves belong to the same family, varying only in their constants.

The range of temperature from A_e (taken as Ac_1) to M_s varies in these twelve steels from 594 to 410° C., and in one attempt to present a general picture of the steels as a whole, the range A_e–M_s was taken as unity and the temperature of transformation expressed as the fraction $f = A_e–B_t/A_e–M_s$, where B_t is the bath temperature.

Plotted in this way, in Fig. 13, are the results of every test made on the twelve steels, and enveloping lines have been drawn. It will be seen that there is a natural division of what are called the lower carbon series and the higher carbon series. In the low carbon series there is unfortunately a gap in the experimental points between $f = 0{\cdot}43$ to $0{\cdot}75$, because the austenites of all the eight steels examined were very stable in this temperature range and the transformation either did not start or was not finished in 24 hr. Although all the points have been included between two straight lines the authors are quite convinced that the mean curve through all the points shows a slight upward bend at the lower temperatures. A statistical examination of the points shows that the change in length on transformation has a temperature coefficient of $7{\cdot}1 \times 10^{-6}$ per degree Centigrade in the pearlite range, but this increases to $10{\cdot}4 \times 10^{-6}$ in the bainite range.

Table IV

EXPANSION DATA—HIGHER CARBON STEELS

Steel	Bath Temp., °C.	$\frac{Ac_1 - B_t}{Ac_1 - M_s}$	Expansion, in./in. × 10^4
L	678	0·094	12·2
	670	0·110	12·7
	650	0·150	12·4
	470	0·511	22·0
	415	0·621	28·4
	400	0·651	28·6
	362	0·727	34·8
	314	0·824	43·0
M	678	0·076	9·5
	670	0·091	10·0
	650	0·127	10·5
	645	0·136	10·5
	634	0·157	12·2
	438	0·513	21·0
	374	0·629	26·5
	345	0·682	31·8
	315	0·736	38·5
	275	0·809	41·0
N	690	0·107	10·0
	656	0·165	11·5
	635	0·200	14·2
	602	0·256	13·8
	370	0·646	29·0
	329	0·715	35·0
	269	0·816	41·2
P	707	0·078	9·5
	680	0·127	11·2
	654	0·175	11·5
	586	0·298	15·4
	545	0·373	18·7
	508	0·440	20·0
	410	0·616	26·5
	358	0·713	35·4
	463	0·522	*26·0[1]
	678	0·131	8·8[2]
	586	0·298	13·8[3]
	586	0·298	13·0[4]

* Austenitizing temperatures: (1) 850° C., (2) 956° C., (3) 950° C., (4) 1000° C.

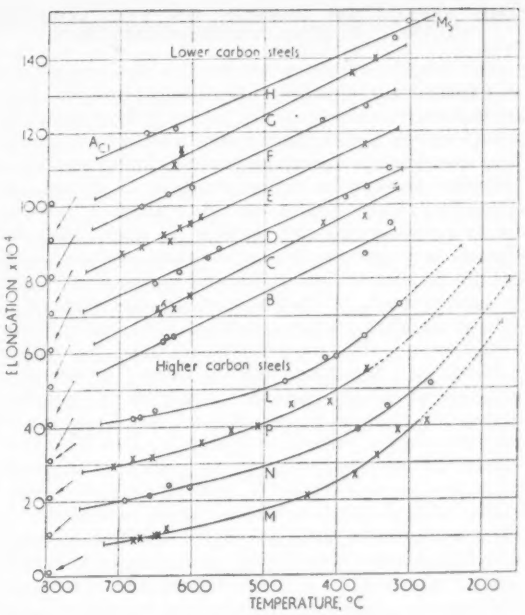

Fig. 12—Length changes per unit length on isothermal transformation of eleven steels

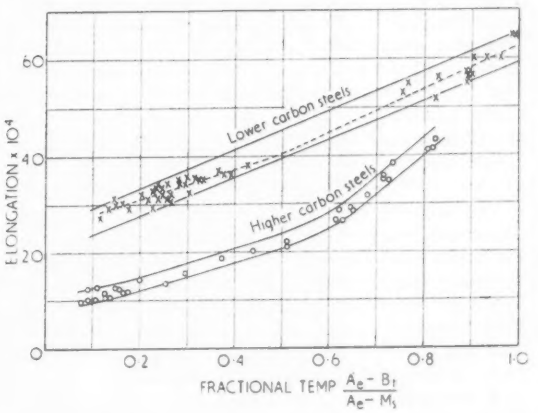

Fig. 13—Length changes per unit length on isothermal transformation plotted against fractional temperature

THE EFFECT OF CARBON ON THE VOLUME CHANGE DURING TRANSFORMATION

The marked difference between the relative amounts of expansion of the low carbon series and the high carbon series is shown in Fig. 13. It follows naturally from two well-known phenomena: when α iron changes to γ iron there is a contraction in volume, and when carbides dissolve in γ iron there is an expansion. The effect of other elements, up to about 3%, seems to be insignificant, and there is no doubt that the change in length or volume depends predominantly on the amount of carbon present in the steel, or, to be more exact, as shown later, on the amount of carbon dissolved in the austenite at the austenitizing temperature. The reverse changes take place when cooling, *i.e.*, the formation of ferrite, either as a pro-eutectoid constituent or as part of the pearlite, causes an increase in length, and the formation of carbides causes a decrease in length. It follows then that if all the products of decomposition of austenite at temperatures between A_e and M_s consisted essentially of aggregates of ferrite which contained, in solution, no more carbon than the equilibrium value, and carbides free from ferritic admixtures, the density after transformation would be the same as an annealed steel at the same temperature. On the other hand, if the temperature of transformation is such that the diffusion of carbide from the austenite is so slow that the $\gamma \rightarrow \alpha$ transformation is completed before all the carbides have separated from it, the ferritic constituent will be supersaturated with carbides. The full effect of the contraction, owing to separation of the carbides originally present, is therefore not felt, and the expansion, owing to the $\gamma \rightarrow \alpha$ transformation, will be greater than if the resulting ferrite were free from carbides. The net result is an expansion greater than would be expected if the final product of decomposition consisted of an aggregate of ferrite and carbides in equilibrium. An attempt has been made to compare these length (or volume) changes quantitatively with the length of a specimen which consists of an equilibrium mixture of ferrite and carbides.

The line *ABCD* in Fig. 14 is the experimentally determined expansion curve, relative to silica, of steel *N* (*see* Table I), starting with the steel in the normalized condition. The A_{cem} temperature of the steel is evidently about 890° C., as judged by the change in direction of the expansion curve at this temperature. The austenitizing temperature in the isothermal transformation tests was 900° C. Beginning from this temperature, the line *DGE* was drawn representing a coefficient of contraction, again relative to silica, of 21×10^{-6}, which was the average of 18 tests.

The vertical lines, at 50° C. intervals, denote the increase in length on isothermal transformation. They are taken from the smooth curve through the experimentally determined points shown in Fig. 12, and although they were corrected for unit length at 0° C. this correction made only a very small difference. The line BFM_s is shown dotted near the M_s temperature, as this part depends on extrapolation.

A comparison of curves *BA* and BFM_s supports suggestions that, at all temperatures between Ac_1 and about 450° C., the products of isothermal transformation are aggregates of ferrite and carbides, of the same degree of purity as found in the slowly cooled steel, and that the change in length is the sum of two quantities: a constant depending on the amount of carbon in the austenite at 900° C., and the difference in the amount of contraction of austenite and pearlite on cooling from Ac to the bath temperature B_t,

$$i.e., E = K + \int_{B_t}^{Ac} (\alpha_A - \alpha_P)dT,$$

where α_A and α_P are the coefficients of thermal contraction of austenite and pearlite respectively.

Below about 450° C. the second term in the expression remains unaltered, but *K* increases continuously down to M_s and depends on the amount of carbide retained in solid solution in the ferrite.

If steel *N* had been austenitized at a temperature just above *C*, the eutectoid change point, it is obvious that the austenite would contain appreciably less carbon than if it had been taken up to 900° C. The effect of this on isothermal transformations would be threefold.

Firstly, the temperature of the beginning of the austenite to martensite change would be raised from 160° C. to about 250° C., thus shortening the range over which it is possible to transform at constant temperature.

Secondly, by drawing a line from *C* parallel to *BGE* in Fig. 14, it can be seen that the length changes should be greater than those found after austenitizing at 900° C. No confirmatory experimental data is available for steel *N*, but Fig. 15 shows this phenomenon for a high carbon, 2% chromium, 1% tungsten steel, *S*. Varying the temperatures from 950 to 1200° C., all above the A_{cem} point, has no

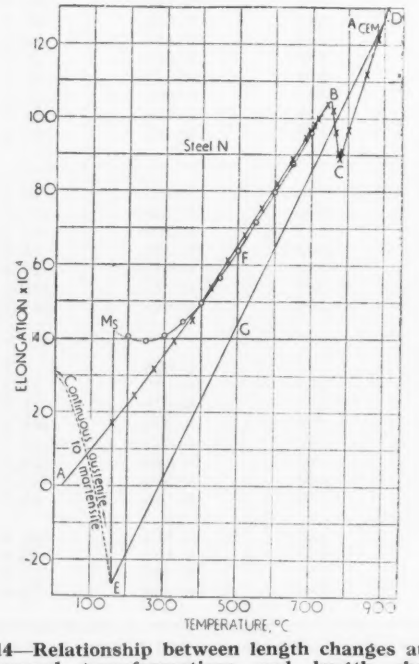

Fig. 14—Relationship between length changes at isothermal transformations and length changes caused by differences in temperature

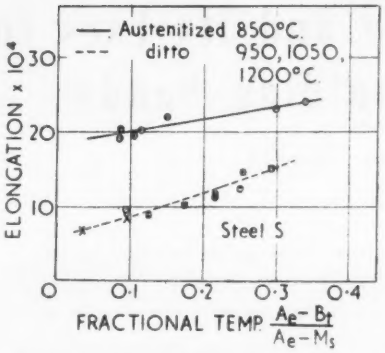

Fig. 15—Effect of austenitizing temperature on length changes of steel *S*

effect on the length changes during isothermal transformation, but with an initial temperature of 850° C., where all the carbides are not in solution, the length changes are very appreciably increased.

Thirdly, the times required for complete transformation at any one temperature would be very considerably shortened. This increased rate of reaction is caused by the nucleating effect of free carbides in the austenite. For a steel of type *N*, the times would probably be reduced to one-tenth of those required when the austenitizing temperature is above the A_{cem} point.

Therefore, if two samples of steel, one austenitized at a temperature above the A_{cem} point, and the other austenitized just above the eutectoid temperature, are allowed to transform isothermally at the same temperature, the sample which has been austenitized at the higher temperature, and which has more carbides in solution in its austenite than the other sample, has very much more time to permit these carbides to separate during transformation. No reason can be advanced why there should be any difference in the final degree of supersaturation of the ferrite with carbide when the transformations of the two samples are complete, and the authors suggest that the line BFM_s in Fig. 14 will represent the length, at temperature, on isothermally transformed steel *N* from all austenitizing temperatures, with the proviso that the line terminates at the M_s characteristic of the austenitizing temperature.

If it is assumed that the percentage volume change during transformation can be calculated from the percentage change in length, this work shows that for both hypo- and hyper-eutectoid steels the increase in volume is almost 2% near the M_s temperatures.

Acknowledgments

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Digging ironstone in Northamptonshire, from the original woodcut by Viva Talbot

The Properties of Olivine and its Uses for Refractories and Moulding Sands

By Kristoffer Johannes Stenvik

SYNOPSIS

Natural olivine and olivine rocks have been known for some time to have valuable refractory properties, and magnesium orthosilicate has been used recently in refractories on an industrial scale. Forsterite ($2MgO.SiO_2$ or Mg_2SiO_4) has been the object of much research during the development of these refractories. Details of the investigations are given, and the properties of forsterite are compared with those of other refractory materials.

Experiments have also been carried out on olivine for use as a moulding sand. Best-quality olivine has a number of technical advantages over quartz for use in foundry operations, and it appears from animal tests that little or no silicosis hazard is involved with the use of olivine sands.

OLIVINE REFRACTORIES

THE discovery in 1925, by V. M. Goldschmidt, that natural olivine and olivine-rock (dunite) had very valuable properties as a refractory material, led to extensive studies on the use of these raw materials for refractories, as several important deposits of these rocks exist in Norway. In recent years, refractories consisting chiefly of magnesium orthosilicate have reached industrial importance. In the development of such industrial refractories in Europe, forsterite ($2MgO.SiO_2$ or Mg_2SiO_4) has been the object of much research work, both in the laboratory and on an industrial scale, preceding by some years the American work on similar refractories.

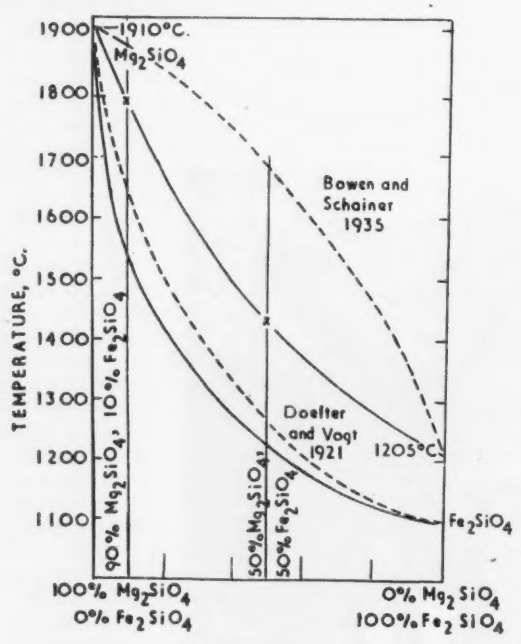

Fig. 1—The Mg_2SiO_4–Fe_2SiO_4 equilibrium diagram, as determined by Bowen and Schainer and Doelter and Vogt

In the course of the early experiments, natural olivine and olivine rocks were found to have valuable refractory properties, despite the content of ferrous orthosilicate (Fe_2SiO_4), which is an extremely fusible substance in the pure state. The melting temperatures of olivines, consisting of about 90% by weight of Mg_2SiO_4 and 10% by weight of Fe_2SiO_4, were stated to be only about 1400° C. by C. Doelter and J. H. L. Vogt (1921) (*see* Fig. 1), but Goldschmidt's experiments in 1926 showed that natural olivine rocks, with as much as 10% of Fe_2SiO_4, could stand up to temperatures (under load) well above 1700° C. Later it was learnt that Doelter had melted his olivine samples in quartz containers, giving fusible clinoenstatite ($MgSiO_3$) by mutual reaction between olivine and silica :

$$Mg_2SiO_4 + SiO_2 \rightarrow 2MgSiO_3 \text{ (fusible at 1560°C.)}$$

The first experimental manufacture of forsterite products was started in 1925–26, and tests were made in Norway on the forsterite bricks in reheating furnaces, ceramic kilns, and gas-fired furnaces, with promising results. The special advantage of the natural olivine rock is its high melting point and the absence of any undesirable transformations during heating, giving an unsurpassed degree of volume stability up to very high temperatures, compared with other natural refractory materials. Olivine also has the unique advantage that no previous calcining is required. The chemical analysis of a typical shipment of rather pure olivine is as follows :

	%		%
SiO_2	41·81	NiO	0·38
MgO	50·31	CoO	0·02
FeO	5·83	CaO	Nil
Fe_2O_3	0·25	$K_2O + Na_2O$	0·01
Cr_2O_3	0·37	TiO_2	Nil
Al_2O_3	0·22	P_2O_5	Nil
MnO	0·12	Ignition loss	0·49

The rock is a dunite and contains, besides olivine, small amounts of enstatite, magnesian amphibole, chromite, and traces of magnetite, phlogopite, corundum, and some secondary serpentine. Some

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Mr. Stenvik is at the Government Laboratory for the Investigation of Raw Materials (Statens Råstofflaboratorium), Oslo, Norway.

(1-6) Common sands, natural bonding clay and 7% coal dust. (7 and 17) Olivine. Wyoming Bentonite 3%, (8 and 16) Belgian yellow sand. (9 and 15) Belgian red sand. (10-12) Common sands without coal dust. (13a, 13b, and 14) Norwegian synthetic sands.

Fig. 2(a)—Refractoriness, burn-on tendency, and surface tension of moulding sands used in Norwegian foundries

[*Stenvik*

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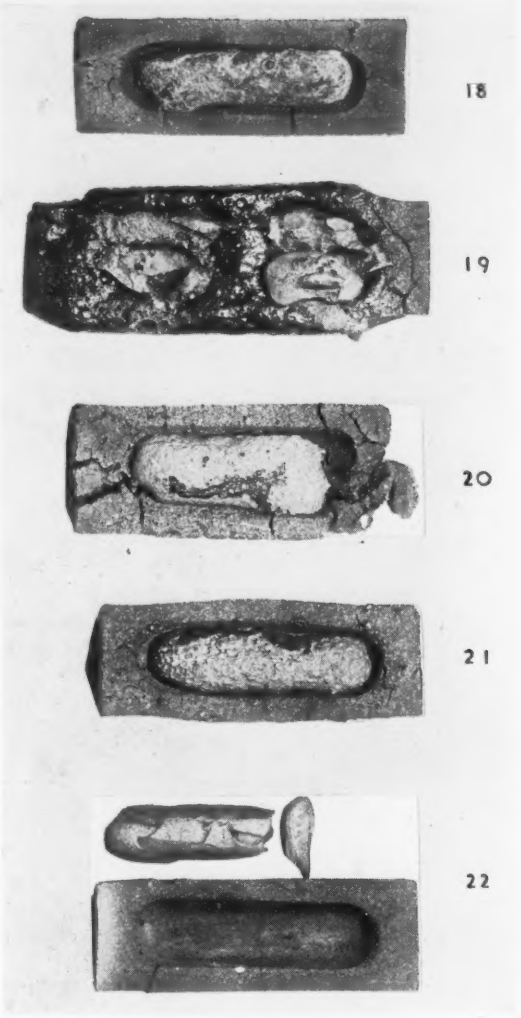
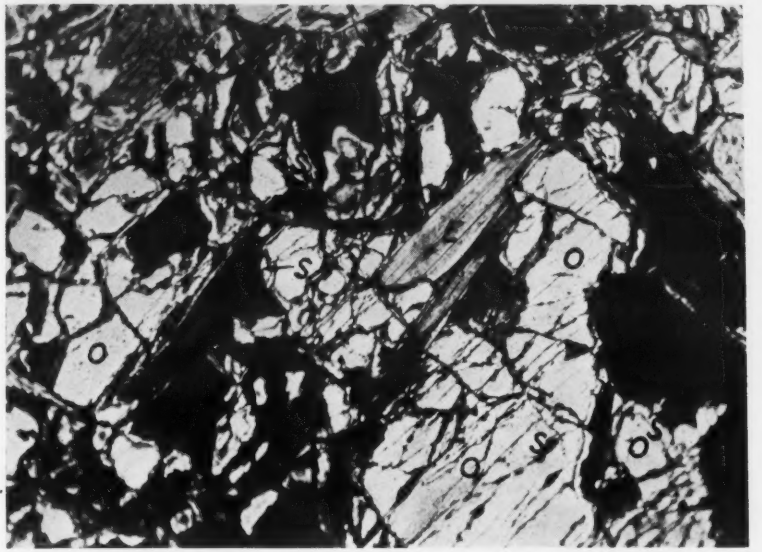


(18 and 21) Common sand without coal dust. (19 and 20) Norwegian synthetic sands. (22) Olivine, Wyoming Bentonite 3%.

Fig. 2(b)—Refractoriness, burn-on tendency, and surface tension of moulding sands used in Norwegian foundries



S=serpentine E=enstatite O=olivine

Fig. 3—Thin section of olivine rock showing hydration products × 100 (approx.)

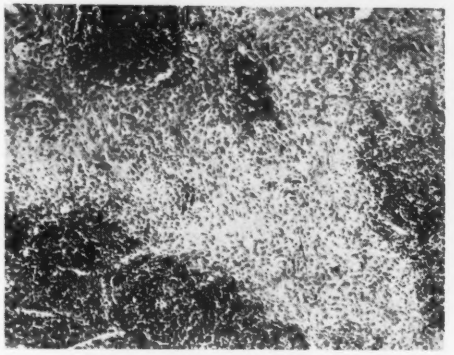


Fig. 4—Bronchial gland of rabbit after exposure to quartz dust for 508 days. The normal lymphoid tissue has been displaced by connective tissue × 100

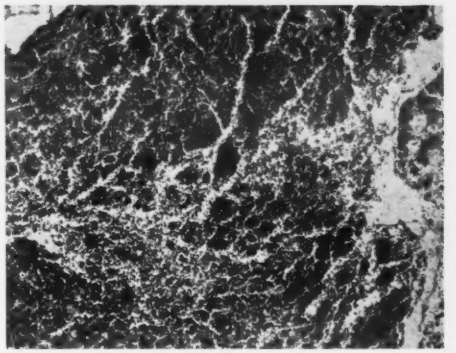


Fig. 5—Bronchial gland of rabbit after exposure to olivine dust for 508 days, showing dust deposit and no fibrous reaction × 100

varieties contain such minerals as diopside, and common secondary minerals are serpentine, talc, and chlorite. The specific gravity of the dunite is about 3·3; the under-load refractoriness of the purest natural olivine rock is very high. Varieties of olivine rock containing serpentine as a product of hydration are somewhat less refractory. A photomicrograph of an olivine rock is shown in Fig. 3.

The olivine rocks are situated on the west coast of Norway, forming lenticular masses in gneissic rocks of granitic or granodioritic composition. The individual deposits of olivine rock are sometimes two miles long and attain a thickness of several hundred yards. Often the olivine rock is accompanied by eclogites.

The development of olivine refractories for industrial uses took place largely from 1928 to 1931, when refractories were made according to Goldschmidt's methods by transforming olivine rock into a mixture of forsterite and magnesium ferrite. The products were tried for various purposes; forsterite bricks were used successfully for high-temperature work in ceramic kilns, and where temperatures above 1600° C. could be attained the chamber walls and roofs were lined with forsterite bricks. Successful experiments were made with an olivine ramming mass for lining induction furnaces for melting non-ferrous alloys and copper–nickel alloys, and forsterite bricks were used in 1930 and 1931 for the arched roofs of copper-refining furnaces fired with gas or powdered coal. The life of the olivine roof is about three times that of the silica roof.

Forsterite bricks are now used in the roofs of copper holding and copper reverberatory smelting furnaces and in the top portion of the lining of converters for blowing scrap brass. In the steel industry they give satisfactory service in the end wall, bridge wall, and ports, of open-hearth furnaces. They are also being used as linings in Portland-cement and dolomite rotary kilns, in walls and roofs of ceramic kilns, and as a source of material for furnace repair in all the industries mentioned above.

Production of forsterite refractories on a commercial scale, from raw material imported from Norway, began in Germany in 1928. In England, forsterite bricks were produced by Holland Pickford, of Sheffield. The success of these bricks in 1936–37 for use in steelworks forging and reheating furnaces served as an impetus for several new markets in Europe.

Properties of Forsterite Refractories

In the following notes, details are given of the main properties of forsterite bricks, and comparisons are made with other refractory materials in common use.

Specific Gravity—The brick weighs about 155 lb./cu. ft., and has a bulk specific gravity of 2·5. This is less than that for magnesite and chrome bricks and higher than that for silica.

Porosity—The range of apparent porosity is 12 to 28% (for insulating bricks 60 to 70%).

Refractoriness—Above cone 38 (1835° C.) the brick is considerably more refractory than silica brick at cone 32 (1700° C.).

Volume Stability—A maximum linear shrinkage of 0·5% takes place when the brick is heated to 1650° C. for 5 hr.

Strength under Load—The cold crushing strength is about 2500 lb./sq. in. The following temperatures are given for under-load tests at 28·4 lb./sq. in.:

Forsterite Brick A

	°C.
Softening temperature	1640
At 1% compression	1710
At 2% compression	1725
At 3% compression	1730
Failure	1737

Slag Resistance—Equal to chrome brick and better than magnesite brick.

posure to quartz dust for 508 days. The normal lymphoid tissue has been displaced by connective tissue × 100

posure to olivine dust for 508 days, showing dust deposit and no fibrous reaction × 100

Fig. 2(b)—Refractoriness, burn-on tendency, and surface tension of moulding sands used in Norwegian foundries

Table I

TEMPERATURES (°C.) OF REACTIONS BETWEEN DIFFERENT REFRACTORIES

A—Reaction first observed B—Reaction became damaging

	Silica		Fireclay		High Alumina (70% Al_2O_3)		Chrome		Magnesite		Forsterite	
	A	B	A	B	A	B	A	B	A	B	A	B
Silica	...		1500	...	1600	...	No reaction		1500	1600	1700	
Fireclay	1500	...	...		No reaction		1600	...	1400	1500	1500	1600
High alumina (70% Al_2O_3)	1600	...	No reaction		...		1600		1500	...	1700	
Chrome	No reaction		1600	...	1600		...		No reaction		No reaction	
Magnesite	1500	1600	1400	1500	1500	...	No reaction		...		No reaction	
Forsterite	1700		1500	1600	1700		No reaction		No reaction		...	

Spalling Resistance—More resistant to spalling than is magnesite brick, but below that of the average fireclay brick. The number of quenching by cold air blast from 1100° C. is :

Forsterite ' regular '	8
Forsterite *A*	12–25
Forsterite *B*	12–25

Thermal Conductivity—Lower than that of silica brick at high temperature.

Thermal Expansion—The expansion rate is uniform, but lower than that of magnesite brick : 1·05% from 20° to 1000° C., 1·5% from 20° to 1400° C.

Unfired refractories consist of crushed olivine and a cold-setting binding agent that will produce a commercial unfired forsterite refractory. The critical factors in the production of this type of refractory are the proper grinding and screening of the olivine and the use of a binding agent that will not lower the pyrometric value of the finished product.

Reaction Temperatures—Temperatures of reactions between forsterite and other refractories, and of reactions between various refractories, are shown in Table I.

OLIVINE MOULDING SANDS

The use of olivine as a foundry moulding sand was first tried on an industrial scale some years ago (Goldschmidt and the author, 1928). Investigations carried out in a number of foundries, using about 1 ton for each test, proved that the material was usable from a technical point of view. These experiments were not continued at that time, however, since the manufacture of olivine refractory bricks offered more favourable marketing possibilities. After studying the industrial uses of olivine refractory bricks (experiments were carried out at the Government Laboratory for Investigations of Raw Materials), the foundry sand tests were resumed.

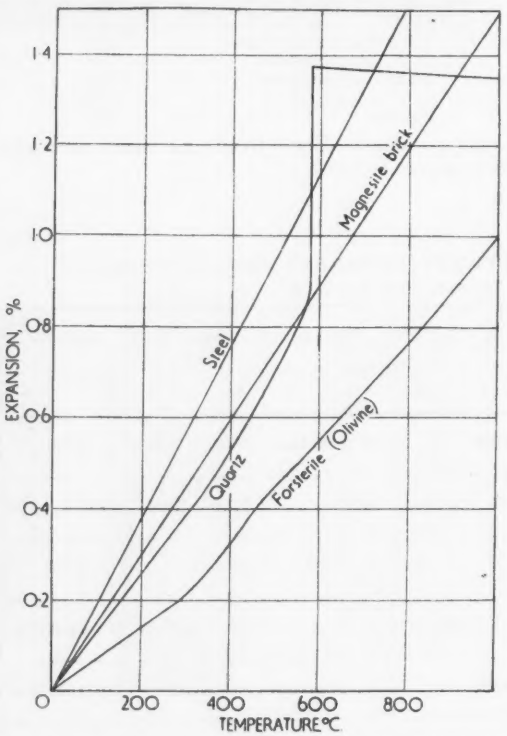


Fig. 6—Thermal expansion of steel, quartz, forsterite, and magnesite brick

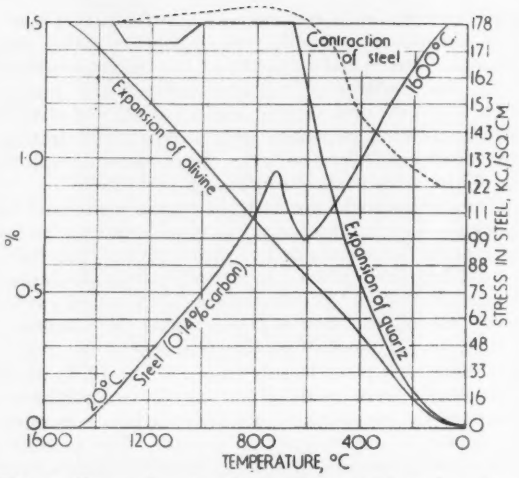


Fig. 7—Expansion for low-carbon steel and olivine and quartz moulding sands

By 1935 the author realized the importance of finding a refractory mineral to replace quartz, which can cause the occupational disease of silicosis. If quartz is used in foundries, moulders, those cleaning the castings, fettlers, and sand mixers, are exposed to quartz dust, thus involving the risk of silicosis. It is the very finest quartz dust, such as is used for paints, dusting powders, etc., which is particularly dangerous.

The author has therefore suggested that dressing paints consisting essentially of olivine instead of quartz should be tried. During 1938 and the following years, such paints were produced at the Government Laboratory for Investigations of Raw Materials, and, together with olivine sand, were supplied to A/S Myrens Verksted, for the casting of the stainless alloy, Termacid (containing about 8% of nickel and 20% of chromium), under close observation. The results were favourable, and further tests were carried out by Raufoss Ammunition Works, Stavanger Electro-Stål A/S, and other firms, in 1939, and by Drammens Jernstoperi (iron foundry) in 1940. In Great Britain, investigations were started by V. M. Goldschmidt, and also by other workers in North America after attention had been drawn to this material through a Canadian Patent by Goldschmidt and the author in 1929.

Tests have also been conducted to determine the reactions between ordinary grey iron and various moulding sands. The results are shown in Fig. 2. The thermal characteristics of various refractory materials are given in Figs. 6 and 7.

The advantages to be gained by the use of olivine sand for foundry operations are partly technical and partly prophylactic. Best-quality olivine is substantially more refractory than is quartz and also

shows greater resistance to scorification of iron oxides, thus preventing the incrustation of sand and scoriae on the surfaces of castings. By the proper use of olivine, a particularly clean surface may be obtained, and the high resistance of olivine to pulverization and scorification makes it last longer than quartz sand.

To benefit from the advantages of olivine, the rock and sand must be protected in transit, storage, and use, against injurious contaminations which impair the hygienic or industrial properties of these materials. Especially, contamination by quartz sand, granite, felspar, talcum, and limestone must be avoided. Aluminous materials are likewise very harmful, because olivine and, for instance, ordinary clay or fireclay, combine by heating to form a silicate of magnesium and aluminium, which very much depresses the temperature of fusion. The chemical equations for some reactions mentioned above are :

$Mg_2SiO_4 + SiO_2 \rightarrow 2MgSiO_3$ (clinoenstatite, softening temperature about 1450° C.)

$Mg_2SiO_4 + CaO \rightarrow MgO + CaMgSiO_4$ (fusible at about 1500° C.)

$Mg_2SiO_4 + 4SiO_2 + 2Al_2O_3 \rightarrow Mg_2Al_4Si_5O_{18}$ (cordierite, fusible at about 1460° C.).

As a bond for olivine sand, only certain special clays, for instance, the American Wyoming bentonite, the Coldbond, and the Ball Clay, can be used, and then only in very small amounts (*e.g.*, 3% minimum by weight of bentonite to 97% by weight of olivine). The Norwegian Olivine Act of 1st March, 1946, assures that every buyer and consumer of Norwegian olivine, both at home and abroad, is offered only high-quality products.

The following are some typical compositions of olivine foundry sands :

Olivine Foundry Sand Compositions

Wt., lb.	Material	Percentage Sand Base
	Green Iron	
1000	0–20 mesh N.B.S. olivine sand	100
20	Bentonite clay*	2
30	Coal dust	3
4	Cereal binder (Totanin)	0·4
	Moisture content 3·5%	
1000	0–8 mesh N.B.S. olivine sand	100
17	Bentonite clay*	1·7
30	Coal dust	3
5	Cereal binder (Totanin)	0·5
	Moisture content 3·5–4%; used for medium and heavy iron castings.	
	Anti-Buckle Iron Facing	
1000	0–40 mesh olivine sand	100
35	Bentonite clay*	3·5
30	Coal dust	3
6	Cereal binder (*e.g.*, Totanin)	0·6
7	Wood flour	0·7
	Moisture content 4–4·5%; used for green-iron castings with large flat areas.	
	Dry Sand Facing Iron	
1000	0–8 mesh N.B.S. olivine sand	100
25	Bentonite clay*	2·5
5	Cereal binder (*e.g.*, Totanin)	0·5
	Moisture content 4–4·5%; used for medium and heavy castings. Spray with blacking, dry at 160–180° C.	
	Cement Sand	
1000	0–20 mesh N.B.S. olivine sand	100
100	Cement	10
5	Bentonite clay	0·5
	Moisture content 6–7%; moulds air-dried for 48–72 hr.; used for light, medium, and heavy castings in steel, iron, and brass. Olivine wash blacking is brushed on and dried in air.	
	Dry Sand Facing Steel	
1000	0–8 mesh N.B.S. olivine sand	100
27	Bentonite clay*	2·7
8	Cereal binder (*e.g.*, Totanin)	0·8
	For cores, add sufficient linseed or other core oil	
	Add oil before water	
	Moisture content 4·5–5%; used for steel, manganese steel, Cr–Ni, Fe–Cr, and Fe–Mn alloys. For moulds and cores, brush on olivine wash for steel, and bake in oven at 160–180° C.	
	Green Steel Sand	
1000	0–20 mesh N.B.S. olivine sand	100
40	Bentonite clay*	4
5	Cereal binder (*e.g.*, Totanin)	0·5
	Moisture content 3·6–4%; used for castings of light and medium weight and size. Should be both moulded and poured on the same day.	

* Swell in water before use

Grading of Olivine Sand

For small and medium-sized pieces, the largest olivine sand grains used in Norwegian foundries are 8 mesh N.B.S. ; the grading is as follows :

Mesh	Percentages
+ 12	3·7
+ 12 to + 30	13·3
+ 30 to + 50	35·0
+ 50 to + 70	15·0
+ 70 to + 140	20·3
+ 140 to + 270	6·0
+ 270	6·0
Water content	0·7

For similar-sized pieces, cement is used as a binder with the following grading :

Mesh	Percentages
+ 12	Nil
+ 12 to + 30	15·2
+ 30 to + 50	42·5
+ 50 to + 70	16·7
+ 70 to + 140	21·0
+ 140 to + 270	3·6
+ 270	1·0

Hygienic Advantages of Olivine

Much attention has been given to the study of the field of health in the use of olivine sand. There are still several open problems in connection with causal factors for silicosis and related diseases. From the beginning of this study, however, it seemed likely that olivine belonged to a more favourable class than quartz and other forms of uncombined silica, including crushed fireclay grog. As pointed out by Briscoe, the results of structure investigations by W. L. Bragg (1920 and the following years) demonstrated that SiO_2 (quartz), after crushing, gives free valences in the surface structure of the dust particles. There is a possibility that these free valences are the cause of,

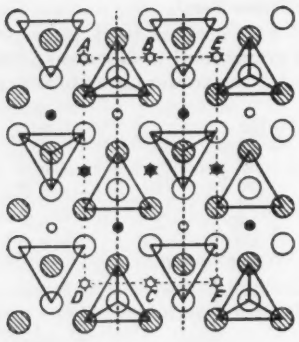


Fig. 8—Lattice pattern of common olivine

or that they contribute substantially to, the very dangerous properties of SiO_2 dust.

Contrary to the SiO_2 structure, each silicon atom of the olivine structure, $Mg_2(SiO_4)$, is bound to four oxygen atoms, thus forming a SiO_4-ion which constitutes a separate unit in the crystal (*see* Fig. 8). This is true for all simple ortho-silicates, and may be the reason why silicosis or related diseases have never been observed in quarrying or mining rock materials containing olivine. Silicosis has never been found in basalt workers (contrary to workers connected with quartzouse sand stones), although the production of road material from basalt rocks has long been established on a very large scale.

The author realized that animal tests were necessary, especially since tests in one foundry suggested that olivine might be more dangerous than quartz. Experiments on rabbits were carried out in Norway by Dr. Elstad and the author in 1940–42, the results of which were published in 1946. In England, experiments with dust from Norwegian olivine were made by E. J. King, V. M. Goldschmidt, and co-workers, in 1943–45, the results being published in 1945. These two series of experiments gave the following result :

After 508 days' exposure to quartziferous dust, the rabbits showed the changes typical of silicosis, both in the lung tissue and in the adjacent bronchial glands, with development of nodules and an increase in the fibrillar connective tissue (*see* Fig. 4). In the rabbits exposed to similar amounts of dust from olivine rock and for the same periods as the rabbits mentioned above, there was only a foreign-body reaction, partly with giant cells, but there was no development of silicotic nodules or increase in the connective tissue (*see* Fig. 5).

From these investigations it may only be inferred that olivine rock offers less danger of silicosis than does pure quartz. Whether or not it is absolutely free from the risk of silicosis is not known. Prolonged exposures might have produced silicotic changes, although chemical investigations of the lungs of the exposed animals, and experiences with other silicates do not favour such a supposition. The average content of silica (SiO_2) found in the lungs of seven animals exposed to quartz was 0·3762 g., and 0·0720 g. in the lungs of seven animals exposed to olivine. The lungs of the animals exposed to quartz dust thus contained more than five times as much silica as the animals exposed to olivine dust. The silica content of olivine is somewhat below half that of quartz. The far larger difference in the analysis of the lungs of the exposed animals seems to indicate a much greater self-purifying power of the lung tissue against olivine dust than against quartz dust. A similar, but different, reaction against various types of silica-containing dust, inferred from chemical analysis of lung tissue, has previously been described (Sundius and Bygdén, quoted by Gardner).

From observations that have been carried out, olivine dust appears to act without irritating the respiratory system into excretion through increased expectoration. The purifying process must therefore be internal, with phagocytes carrying the dust away and other organs excreting it in a dissolved or unchanged form.

From the experimental results mentioned in this paper, it may be inferred that inhalation of dust particles from olivine rock will give very slight or no risk of silicosis. With the application of olivine as a moulding sand, the danger connected with free silica is removed, and it may be a means of eliminating the silicosis hazard in this industry.

The experiments made by E. J. King and V. M. Goldschmidt gave this result : " The changes produced in the lymph nodes are slight, consisting of an increase in the reticulin fibres. The reaction to olivine is thus of simple foreign-body type. There is no formation with reticulin fibrosis. The dust appears to be non-toxic in comparison with silica."

At the suggestion of V. M. Goldschmidt, corresponding experiments on animals were carried out in the U.S.A. during the years 1943–45, and these have fully confirmed the harmless nature of olivine. Mr. Leroy U. Gardner, Director at the Saranac Laboratory, Saranac Lake, N.Y., sent a report on these experiments to V. M. Goldschmidt. The following is taken from this report : " You can conclude that Norwegian olivine is inert and incapable of causing pulmonary damage if inhaled." . . . " I have two animals of the series alive, and I think I will allow them to live as many years as they will, as I have not the slightest reason to anticipate that there will be any further change. Collateral tests were made in both guinea pigs and rabbits on the sample of American olivine supplied to us by Harbison-Walker Refractory Company. These likewise showed no suggestion of irritating properties. We have two rabbits of this series surviving which will likewise be allowed to live out their days in order to convince people that olivine is a harmless silicate."

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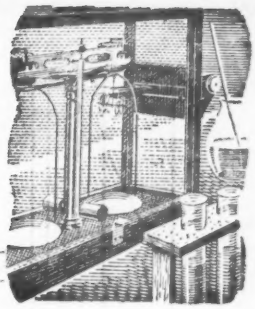

The Acceleration of the Rate of Isothermal Transformation of Austenite

By M. D. Jepson, M.Sc., and F. C. Thompson, D.Met., M.Sc., F.I.M.

SYNOPSIS

Part I describes the effect of a fluctuating temperature of the transformation bath, a marked decrease in the transformation time being observed in the martensite range. Most of the transformation occurs during the cooling part of the temperature cycle.

Part II deals with the effect of stress on the rate of isothermal transformation which has been examined over a range of temperatures, both tensile and compressive stresses being investigated.

Tensile stresses of the order of 10 tons/sq. in. are found to accelerate markedly the decomposition of austenite at constant temperature. Compressive stresses of a higher order seem to be required to produce a comparable effect. Below a certain minimum stress, little or no acceleration occurs, and the increase in the rate of transformation becomes greater as the stress is increased.

Stresses of a fairly high order are shown to have an effect on the distribution of low temperature bainite.

A simple, rapid, and sufficiently accurate method of following the course of the transformation, by measuring the load required to break notched test-pieces, is described.

PART I—THE EFFECT OF TEMPERATURE OSCILLATION ON THE RATE OF TRANSFORMATION OF AUSTENITE

THE possibility of accelerating the rate of breakdown of austenite by means of thermal oscillations, was considered on the grounds of Thompson and Stanton's stress-relief theory,[1] since temperature fluctuations might assist in the relief of internal stress. As the work proceeded it was realized that other explanations of the results obtained fitted the facts more closely than this very tentative hypothesis, and these are discussed more fully later.

The normal quenching bath of the Stanton dilatometer[2] was replaced by one specially designed to produce a regular variation of the temperature of the quenching medium, and a sectional diagram of it is shown in Fig. 1. A thin-walled brass beaker containing the quenching liquid, in this case oil, was surrounded by a copper tube. In the air gap between the tube and the beaker, a coiled 1000-watt nichrome heating element was mounted on fire-clay rods. Air holes were provided in the asbestos discs carrying these rods, so that a current of air could flow through the annular space. This assembly was mounted in a case and raised above the platform of the dilatometer to allow air to circulate freely. In this form it was found that the rate of cooling was too slow, to remedy which a motor-driven fan was mounted on ball bearings under the furnace. Since it was required to drive the fan only when the bath was cooling, a time switch automatically started and stopped the fan at the same time as the furnace heater was switched off and on respectively.

The range of the temperature cycle, which was complete in 5 min., varied with the average bath temperature from $\pm 2\frac{1}{2}$° C. at 150° C. to $\pm 7\frac{1}{2}$° C. at 300° C. The quenchings were done from a fixed temperature, allowance being made for the rise in the bath temperature resulting from the introduction of the hot specimen and holder. Comparative quenchings were also carried out without this temperature fluctuation.

For most of the work a eutectoid plain carbon steel, *A*, of the following composition, was used :

C, %	0·84	P, %	0·033
Si, %	0·22	Ni, %	0·12
Mn, %	0·53	Cr, %	0·09
S, %	0·049	Cu, %	0·12

For confirmatory purposes, work was also carried out on a second steel, *B*, which contained 1% of carbon.

Steel *A* was quenched from 800° C. (steel *B* from 900° C.) into baths at temperatures ranging from

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Mr. Jepson is a physical metallurgist in the Research Department of Messrs. Hadfields, Ltd.

Professor Thompson is Professor of Metallurgy at Manchester University.

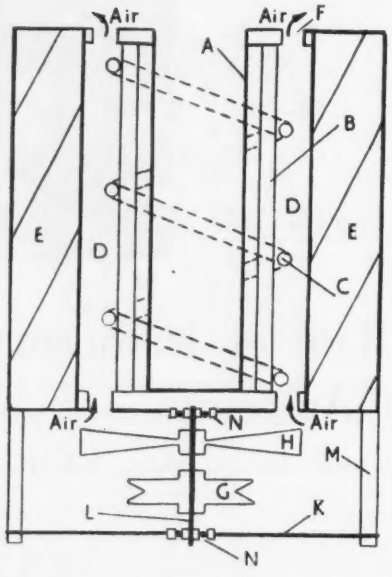


Fig. 1—Furnace for oscillated quenches. *A*, Oil bath; *B*, Fire-clay rods; *C*, Heating element; *D*, Air gap; *E*, Asbestos-wool insulation; *F*, Air holes; *G*, Driving pulley for *H*; *H*, Cooling fan; *K*, Cross-strips carrying axle; *L*, Axle; *M*, Legs to leave air passage under furnace; *N*, Ball races carrying axle

130° C. to 200° C., above which temperature the quenching oil took fire. Dilatation/time curves were obtained for every quench, and from these the time required for the transformation to reach completion was measured. These transformation times, confirmed by repeat quenches, are plotted against temperature in Fig. 2, the curves representing 100% transformation under isothermal or oscillating temperature conditions.

In the lower temperature range the acceleration of the breakdown of the austenite, owing to the fluctuating temperature, is very clearly shown. As the transformation temperature rises, however, the curves approach each other, and at about 250° C. the difference is of the order of the experimental error. Most of the effect of the oscillation seems, therefore, to be confined to the martensite range.

The reason for this acceleration of the breakdown of the austenite is apparent from the shape of the dilatometric curves, of which a typical one is reproduced in Fig. 3*a*. Figure 3*b* shows some sections of this curve enlarged and related to the heating and cooling cycle. The jumps which occurred when the heating and cooling cycles replaced each other were still found when a control specimen, in which no transformation was taking place, was substituted, and later proved to be caused by electrical interference from the fan motor. They may therefore be ignored. It becomes clear that the increase in length of the specimen takes place, in the main, during the cooling part of the cycle, when the marked accelera-

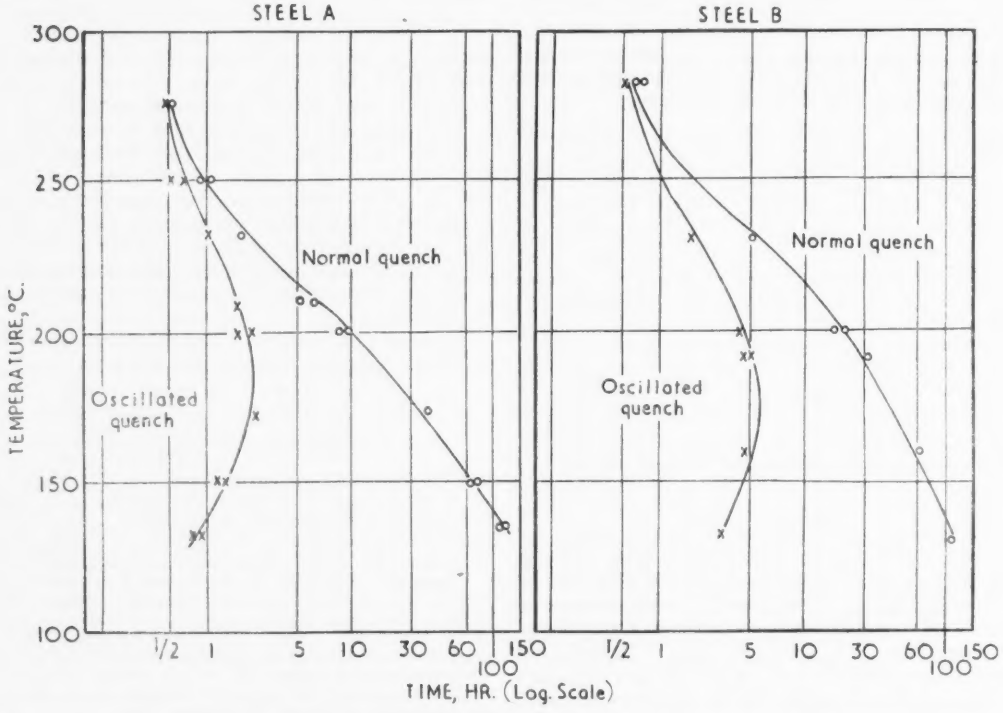


Fig. 2—Transformation/time/temperature curves showing the effect of temperature fluctuation. Curves represent end of isothermal transformation

tion occurs. It may be noted that the transformation is not necessarily stopped during the heating stage, as it has been shown that transformation in the martensite range still takes place, though more slowly, even when the temperature is definitely rising.[3]

PART II—THE EFFECT OF STRESS ON THE RATE OF TRANSFORMATION OF AUSTENITE

It is known that, when partial transformation of austenite occurs, particularly to martensite, there is a marked tendency for the breakdown to take place preferentially at the surface of the specimen. The experiments of Benedicks[4] were the first to point to a satisfactory explanation of the phenomenon. On this hypothesis, the skin of martensite first formed, retards further expansion in the interior of the specimen and thus, together with any compressional stresses set up, inhibits further breakdown. Subsequently, Thompson and Stanton[1] reported that when relatively large specimens were transformed isothermally a distinct skin effect was generally observed, this being explained in a similar way.

It therefore seems likely that the imposition of a tensile stress during the transformation, by opposing this compression, would tend to facilitate the transformation of the specimen as a whole.

More recently, work by Cottrell[5] on the tensile properties of an air-hardening steel during transformation resulted in the suggestion that any form of stress sufficient to produce plastic deformation would increase the rate of breakdown of austenite.

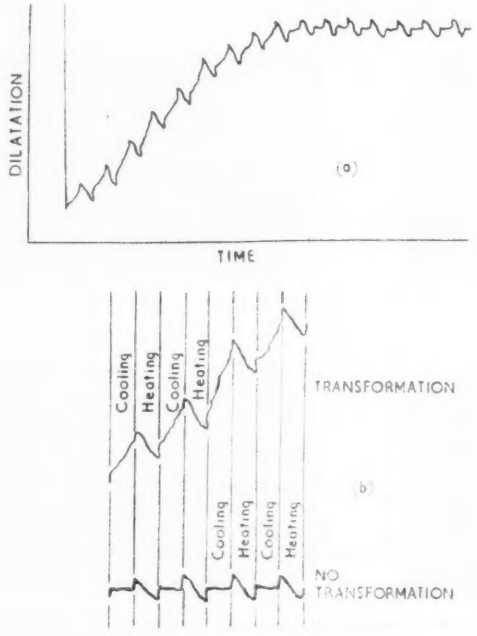


Fig. 3—(*a*) Dilatation/time curve. Oscillated quench; (*b*) Enlarged sections of dilatation/time curve

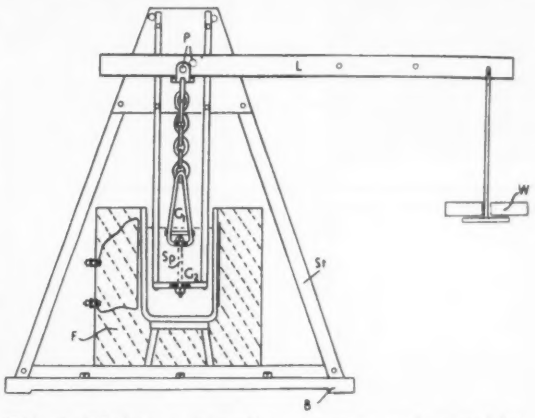


Fig. 4—Diagram of tensile apparatus and quenching bath. *B*, Cast-iron base plate; *F*, Furnace; G_1, Upper grip; G_2, Lower grip; *L*, Lever; *P*, Pivots; *Sp*, Specimen; *St*, Angle-iron stand; *W*, Weight on stirrup

It was decided, therefore, to investigate the effect of both tensile and compressive stresses imposed while the material was transforming isothermally.

TENSILE STRESS

The equipment necessary to impose a tensile stress in specimens during transformation made the use of the dilatometer impossible, and the progress of the transformation was followed metallographically.

It was decided, in addition, to measure the notch toughness of the specimens by means of a slow bend test. These determinations were found to vary during transformation in a way which suggested that they

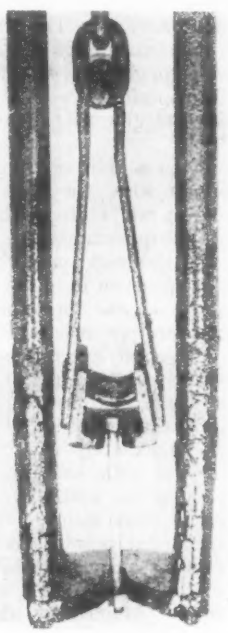


Fig. 5—Grips of tensile machine. Approx. half size

Table I

SPECIMENS UNDER TENSILE STRESS. QUENCH 800° C./280° C. STRESS 10 TONS/SQ. IN.

Transformation Time, min.	Breaking Load, lb.		Transformation, %	
	Stressed	Normal	Stressed	Normal
5	280 290	130 120	45	5
10	550 510	200 250	90	50
20	690 720	350 400	100	80
35	730 710	650 680	100	100
60	710 740	750 710	100	100

would form a valuable method of measuring the time required for complete transformation.

Experimental Procedure

The apparatus consisted of a very simple tensile machine so arranged that both grips were submerged in the quenching medium (Fig. 4). The load was applied by means of a lever, *L*, and weights of 10, 15, and 20 lb. on the stirrup, corresponding to stresses of 10, 15, and 20 tons/sq. in. on the specimen.

It was clearly essential that the specimen should be gripped as rapidly as possible, even though the grips were submerged in the quenching medium. The specimens used were of steel *A*, with a diameter of 0·16 in., and a length of 2½ in., on each end of which was screwed a 3BA steel nut. The grips were plates, each with a cut sufficiently large for the shank of the specimen to pass through, yet capable of holding the nuts (Fig. 5). The specimens were threaded and the nuts screwed down to give a ' gauge length ' of two inches.

After mounting on a thin steel carrying rod, by means of nichrome wire, they were placed in a furnace, and held at 800° C. for 5 min. They were then plunged into the quenching bath, at once slipped into the grips, and the load applied ; the time from the removal of the specimen from the heating furnace until it was under load was approximately 15 sec.

To obtain comparative results for normal conditions, other, unstressed, specimens were subjected to the same isothermal treatment. All specimens were quenched out in cold water immediately the required transformation time had elapsed.

It was found immediately that the steel, when immersed in a solder bath, broke under a stress of less than 10 tons/sq. in. within a few minutes of applying the load. These failures were found to be caused by intergranular penetration of the stressed steel by the molten solder used as the quenching medium. It was also found that almost complete protection could be obtained by nickel-plating the specimens. Since nickel-plating also served to prevent decarburization, all specimens were plated before use.

After treatment each specimen was notched in two places by means of a carborundum-loaded copper wire, and the breaking load, under a slowly applied bending stress, was measured on a Hounsfield Tensometer. The middle third of each specimen was then mounted in Diakon and prepared for microscopic examination.

The ranges of temperature which could be employed were fixed firstly by the mechanical properties of the material, and secondly by its rate of transformation. The first factor restricted the range between 220° C. and 660° C. Below this range the specimens were so brittle that the non-axial loading, inherent in the simple grips used, caused fracture almost immediately the load was applied. The upper limit was determined by the ductility of the specimens, since at temperatures over 660° C. the nuts pulled off. The time taken to set up the specimen in the grips, about 15 sec., made the measurement of small transformation times, say less than 1 min., either inaccurate or impossible. This rate of transformation obtains for steel *A* for temperatures between about 400° C. and 640° C., which range also was beyond the scope of the present apparatus.

Thus the temperature ranges investigated were 220° to 400° C., with molten solder as the quenching medium, and 640° to 660° C. in molten lead.

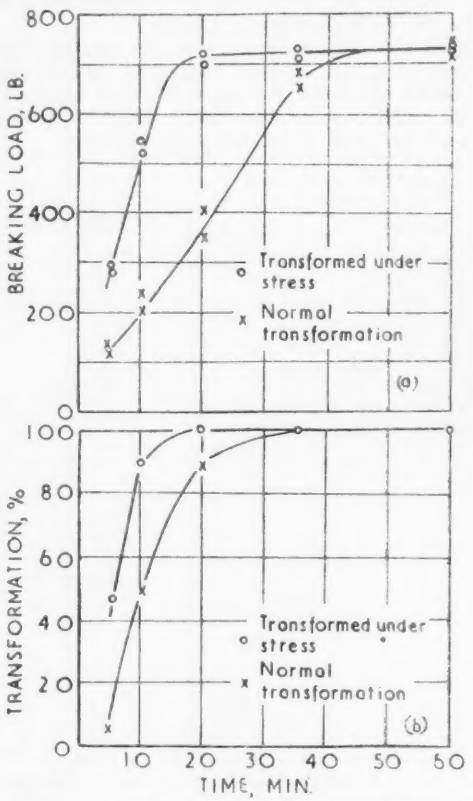
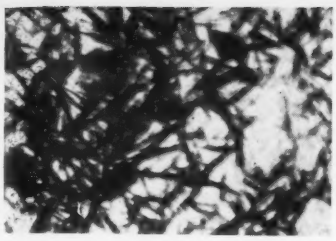


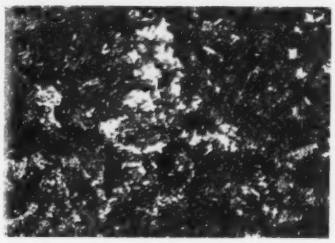
Fig. 6—Transformation under tensile stress 800/280° C. 10 tons/sq. in. (*a*) Variation of breaking load against transformation time; (*b*) Estimated percentage transformation against time



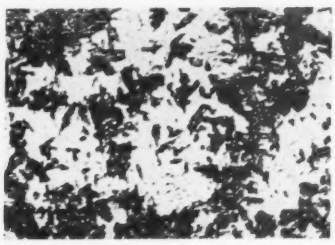
(a) Quench 800/280° C. Transformation time 5 min.

(b) × 1000

(c) × 1400
Quench 800/350° C. Transformation time 3 min.

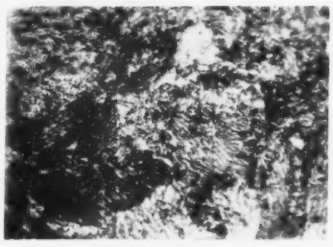


(d) Quench 800/400° C. Transformation time 1 min.

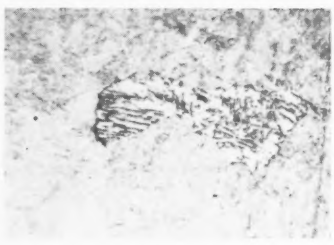


(e) × 600

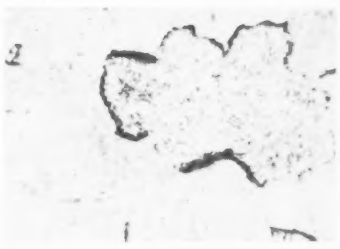
Fig. 7—Microstructures of specimens subjected to tensile stress of 10 tons/sq. in. *(a)* and *(d)*, stressed quench ; *(b)* and *(e)*, normal quench



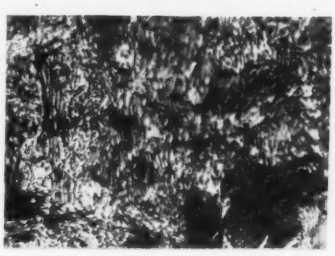
(a) 1 min.



(b) 1 min.



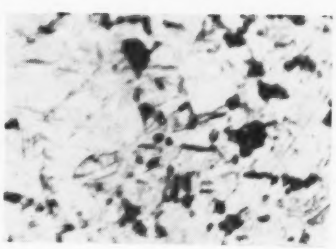
(c) ½ min.



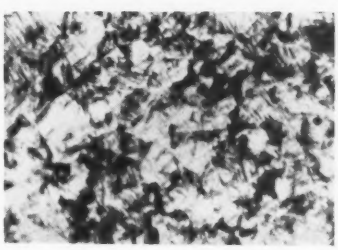
(d) 2 min.

(e) 2 min.

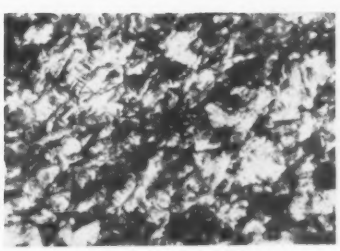
Fig. 8—Microstructures of specimens subjected to tensile stress of 10 tons/sq. in. Quench, 800/645° C. *(a)* and *(d)*, stressed quench ; *(b)*, *(c)* and *(e)*, normal quench. Etched with 4% nital. Transformation times as shown × 1000



(a) 7 tons/sq.in.



(b) 20 tons/sq.in.



(c) 50 tons/sq.in.

Fig. 9—Microstructures of conical specimens subjected to compressive stress. Quench, 800/280° C. Transformation time, 10 min. Etched with 4% nital × 400

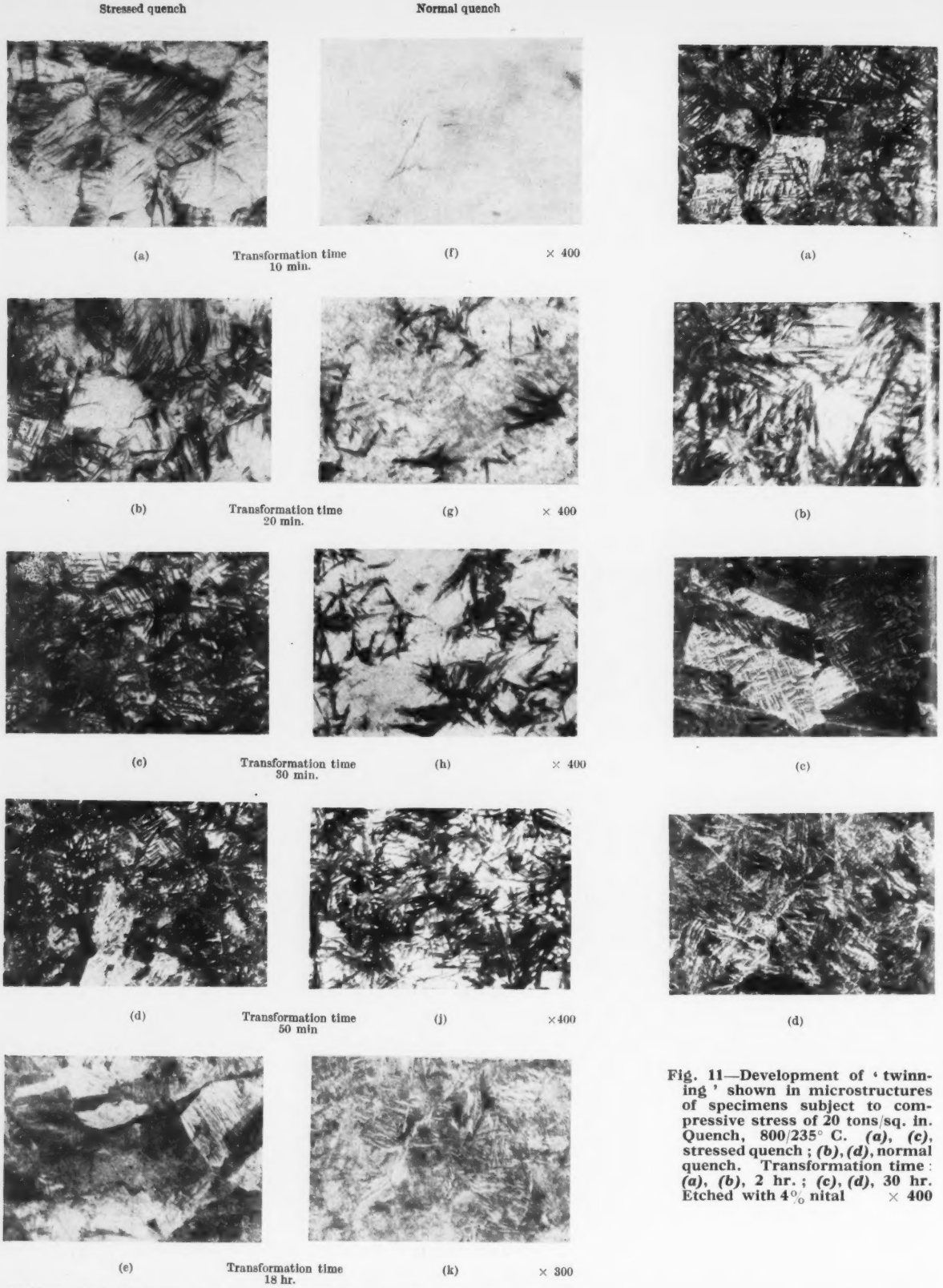
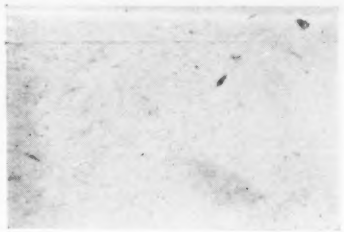


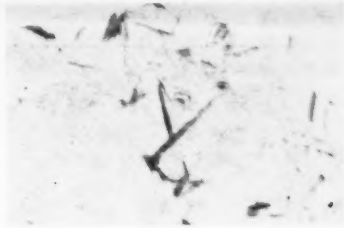
Fig. 10—Microstructures of specimens subjected to compressive stress of 20 tons/sq. in. Quench, 800/270° C.

Jepson and Thompson

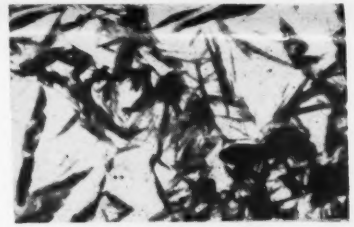
Fig. 11—Development of 'twinning' shown in microstructures of specimens subject to compressive stress of 20 tons/sq. in. Quench, 800/235° C. *(a)*, *(c)*, stressed quench; *(b)*, *(d)*, normal quench. Transformation time: *(a)*, *(b)*, 2 hr.; *(c)*, *(d)*, 30 hr. Etched with 4% nital × 400



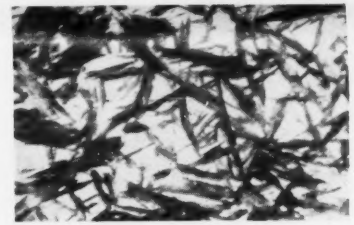
(a)



(b)

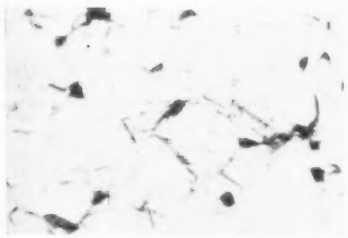


(c)



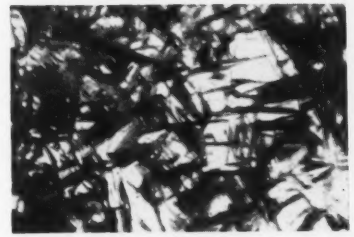
(d)

Normal Quench



Transformation times (e) 2 min.

(f) 4 min.



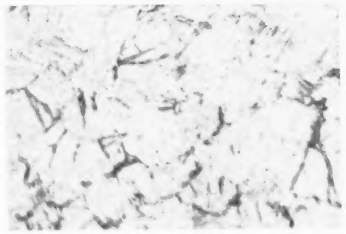
(g) 7 min.

(h) 11 min.

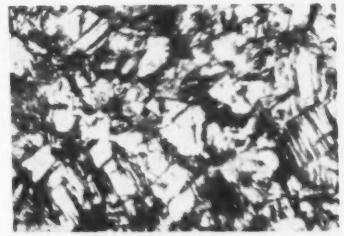
Stressed Quench

Fig. 12—Microstructures of specimens subjected to compressive stress of 20 tons/sq. in. Quench, 800/300° C. Etched with 4% nital × 600

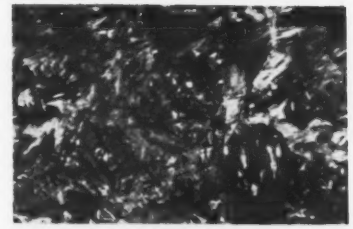
(a) 1 min.



(b) 2 min.



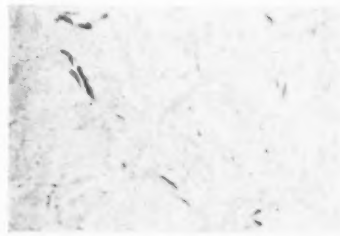
(c) 5 min.



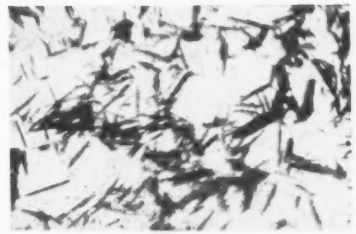
(d) 10 min.

Stressed Quench

Fig. 13—Microstructures of specimens subjected to compressive stress of 20 tons/sq. in. Quench, 800/340° C. Etched with 4% nital × 350



Transformation times (e) 2 min.



(f) 5 min.

(g) 10 min.

Normal Quench

Upton and Thompson

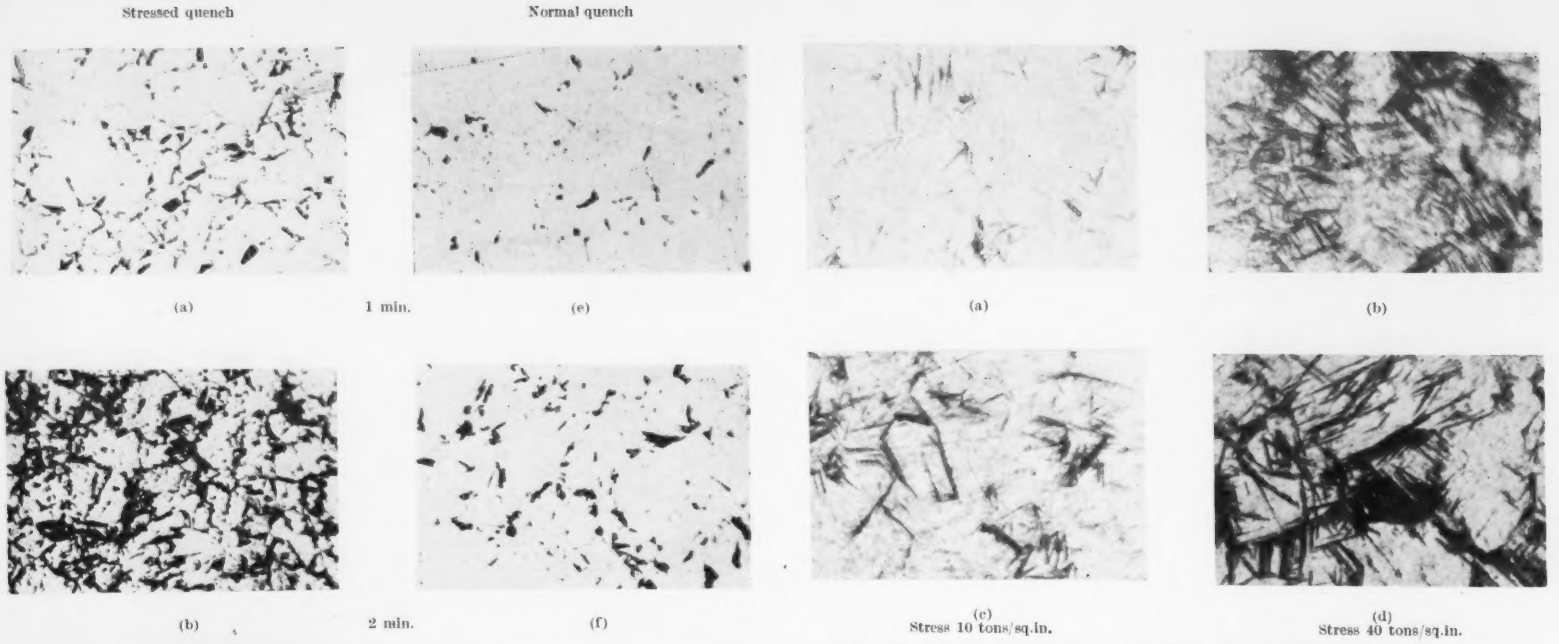
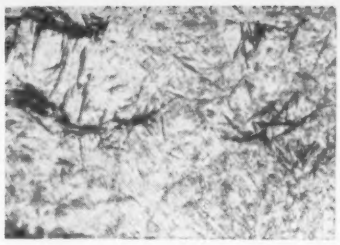


Fig. 15—Microstructures of conical specimens subjected to compressive stress. Etched with 4% nital × 600

Fig. 14—Microstructures of specimens subjected to compressive stress of 20 tons/sq. in. Quench, 800/375° C. Etched with 4% nital. Transformation times as shown × 350

(a) Nil



(b) 7 tons/sq.in.

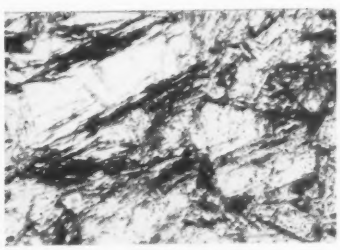
(c) 14 tons/sq.in.

(d) 20 tons/sq.in.

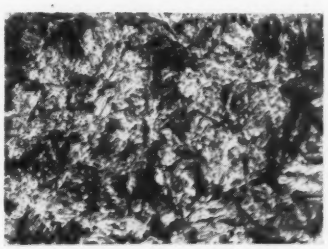
(e) 200→50 tons/sq.in.

Fig. 16—Microstructures of specimens subjected to compressive stress. Quench, 800/270° C. Transformation time, 20 min. Etched with 4% nital. Stresses as shown × 350

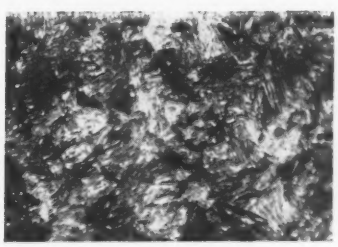
(a) Nil



(b) 7 tons/sq.in.



(c) 14 tons/sq.in.



(d) 20 tons/sq.in.

Fig. 17—Microstructures of specimens subjected to compressive stress. Quench, 800/235° C. Transformation time, 2 hr. Etched with 4% nital. Stresses as shown × 350

BREAKING LOAD ON NOTCHED BAR, LB

After some preliminary experiments a stress of 10 tons/sq. in. was taken as standard for all subsequent treatments.

Results

The general form of the results obtained at each temperature investigated was much the same; the values obtained at 280° C., therefore, are given in full, and the remaining results are recorded in tabular and/or graphical form.

Apart from subsequent repeat quenches, five pairs of specimens were quenched from 800° C. into a bath at 280° C. It was known from the isothermal transformation diagram that under normal conditions, transformation at this temperature should be complete in about 30 min. To obtain a succession of results, so that a percentage transformation/time curve could be constructed, pairs of specimens were held in the bath for periods of 5, 10, 20, 35, and 60 min.

The values of the breaking loads of these specimens, together with the percentage transformation estimated from the microstructures, are given in Table I. On plotting these figures against the transformation time, it was noted that the curves of breaking-load/time (Fig. 6*a*) and percentage-transformation/time (Fig. 6*b*), were of much the same shape. In each case the curves rose rapidly to a maximum value and subsequently remained constant, the maximum being attained in approximately the same time. Further, in both curves, that representing the transformation (or toughness) of the stressed material rose to the maximum considerably ahead of that resulting from the normal, *i.e.*, unstressed, treatment.

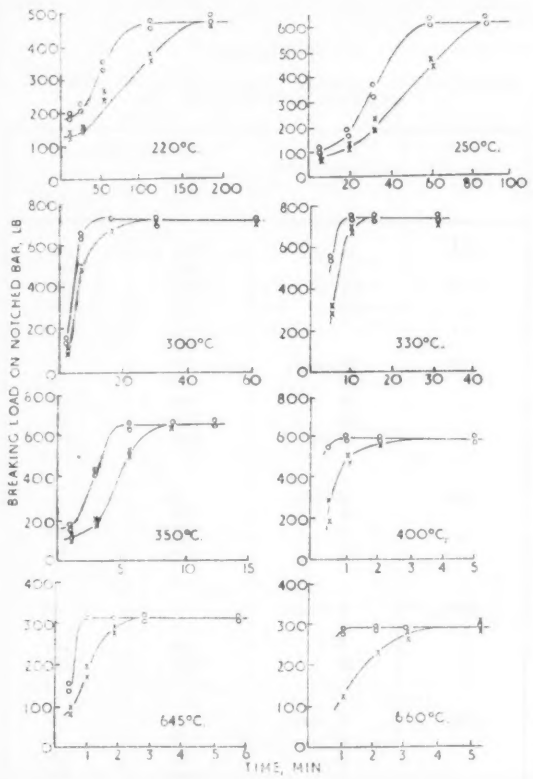


Fig. 18—Breaking-load/time curves of specimen transformed under tensile stress. Stress 10 tons/sq. in.

Table II

SUMMARY OF RESULTS AND COMPARISON BETWEEN DILATOMETRIC, MICROSCOPIC, AND MECHANICAL METHODS OF ESTIMATING TRANSFORMATION TIME UNDER TENSILE STRESS. STRESS 10 TONS/SQ. IN.

Transformation Temp., °C.	Transformation Time, min.				
	'Normal' Quench			'Stress' Quench	
	Dilatometric	Microscopic	Notch-Bend	Microscopic	Notch-Bend
220	180	...	210	...	80
250	80	...	75	...	45
280	40	35	40	15	17
300	30	25	25	8	10
330	15	15	14	7	7
350	14	...	12	...	4
400	...	6	4	2½	2
645	...	2½	2½	1	1
660	...	5	4½	2	2

The product of the transformation was a normal, fairly fine, acicular bainite, as will be seen from the micrographs (Figs. 7*a* and *b*), and no indication was obtained in these experiments that any change in the character of the products was produced by the application of the stress of 10 tons/sq. in. However, there is a considerable increase in the rate of transformation, the time required for complete transformation being 35 to 40 min. under normal conditions, compared with 15 to 17 min. under stress.

The remainder of the results of the bend tests, covering temperatures of 220° C., 250° C., 300° C., 330° C., 350° C., 400° C., 645° C., and 660° C. are shown in Fig. 18. Certain photomicrographs illustrating the structures obtained are given in Figs. 7 and 8.

As a check on the conclusion that the time to reach the maximum breaking strength and the transformation time were identical, the results of mechanical and microscopic examination were compared with dilatometric values. This, of course, was possible only in the case of the normal quench, but, as will be seen from Table II, the comparison was very good. Table II also summarizes the general effect of tensile stress on the time necessary for transformation to become complete. These figures were used to plot the transformation/time/temperature curves in Fig. 19, and these curves show that, for the steel used, a stress of 10 tons/sq. in. will approximately double the rate of transformation at the temperature investigated.

COMPRESSIVE STRESS

The machine used for the tensile experiments required only slight modification to make it suitable for the imposition of compressive stress. A compression rod of heat-resisting steel was substituted for the chain and upper grip, and the pivoting of the lever altered to give compression instead of tension.

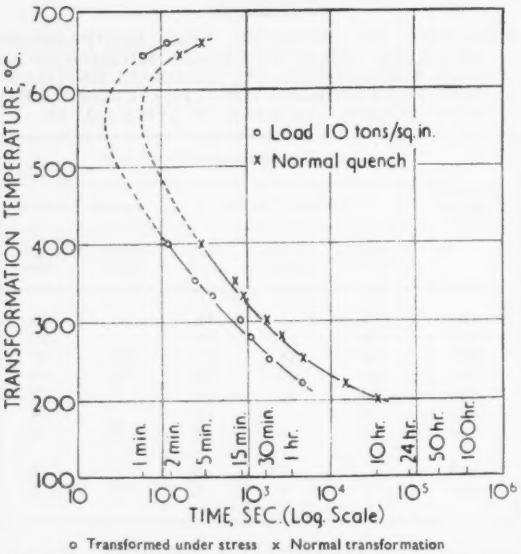


Fig. 19—Transformation/time/temperature diagrams for stressed and normal quenches

Only the lower temperature range, between 200° C. and 400° C., was investigated ; investigations into the higher range included in the tensile experiments proved to be impossible, as the strain produced was too great for the modified machine. The other factors remained the same.

Preliminary experiments, using fairly large specimens which enabled stresses of 5–10 tons/sq. in. to be obtained, showed this order of stress to have no measurable effect. To obtain higher stresses, and also to examine a range of stress within each specimen, conical specimens were ground from the rod. This resulted in a stress range of 6–60 tons/sq. in. down the length of the specimen. A test quench on such a specimen from 800° C. into a bath at 280° C. showed, for a transformation time of 10 min., that quite a marked effect was produced under the higher stresses. This is indicated by Fig. 9 and by the hardness figures given below.

Quench 800°/280° C.	Transformed for 10 min.
5–7 tons/sq. in.	850 V.P.N.
20–25 ,, ,,	832 ,,
50–55 ,, ,,	780 ,,

The stress figures given are approximate, being calculated from the applied load and the cross-sectional area at the level at which the readings were taken.

With these conical specimens the stress at any point could only be estimated, and the rather large diameter of 0·35 in. at the base was found to be too great to obtain an efficient quench. It was, therefore, decided to use smaller cylindrical specimens of steel *A*, having a diameter of 0·16 in. and a length of 0·3 in. Stresses of up to 20 tons/sq. in. could be imposed directly on these specimens, and higher stresses, if required, could be obtained by again grinding them to a conical form.

Experimental Procedure

Pairs of specimens were mounted on a single carrier, one held vertically so that it could conveniently be inserted under the compression rod, the other being fastened horizontally so that no stress was applied.

Two series of experiments were carried out. In the first, the same stress, 20 tons/sq. in., was used, and the transformation time was varied. In the second the transformation time was fixed and the imposed stress was varied. The progress of the transformation was, in all cases, followed microscopically. Estimates of the percentage transformation were made in order to illustrate the results graphically, though it is realized that these may be subject to a considerable personal error.

Results

In the first series of experiments with a constant stress of 20 tons/sq. in., just as in the tensile experiments, the trend of the results at each temperature was closely similar, and therefore only one temperature of 270° C. will be considered in detail.

The cylindrical specimens were quenched after 5 min. at 800° C. Five pairs of specimens were treated at this temperature. The transformation times and results are given in Table III, and photomicrographs of the sections are shown in Fig. 10.

From these structures the times required for complete transformation were estimated to be :

(*a*) Loaded to 20 tons/sq. in. 35 min.
(*b*) Normal transformation 60 min.

The fine bainitic structure does not appear to be altered by the imposition of stress, but in the early

Table III

SPECIMENS UNDER COMPRESSION STRESS. STRESS 20 TONS/SQ. IN.

Temp., °C.	Transformation Time	Transformation, %	
		Stressed	Normal
235	2 hr.	100	80
,,	6 ,,	100	100
,,	18 ,,	100	100
,,	30 ,,	100	100
270	10 min.	10	1
,,	20 ,,	40	5
,,	30 ,,	95	10
,,	50 ,,	100	60
,,	18 hr.	100	100
300	2 min.	5	< 1
,,	4 ,,	15	5
,,	7 ,,	50	20
,,	11 ,,	80	50
340	1 min.	1	< 1*
,,	2 ,,	5	1
,,	5 ,,	75	25
,,	10 ,,	100	90
370	1 min.	5	1
,,	2 ,,	20	5
,,	3 ,,	60	15
,,	5 ,,	100	85

* Denotes specimens not shown as photomicrographs

stages of transformation under stress a marked parallelism of the needles in any one austenitic grain is evident (Fig. 10*a*). At a later stage this gives an appearance suggestive of twin bands, the effect becoming very marked if the treatment is continued long after the transformation has been completed (Figs. 10*a* and 11).

In the earlier stages the similarity of this ' preferred orientation ' of the needles to slip bands is quite remarkable. Certain grains, apparently those which were most suitably orientated, showed a much higher degree of transformation than the remainder. In these grains in particular, the direction of the imposed stress and the direction the majority of the needles were inclined at an angle of about 45°, *i.e.*, the transformation had occurred preferentially on the planes of maximum shear stress.

The experimental conditions and estimated numerical values of the remainder of the results of this series of experiments are tabulated in Table III, and from them the isothermal transformation curves shown in Fig. 20 were plotted. Typical structures are illustrated in Figs. 12–14.

The distributional effect noted at 270° C. became less noticeable at higher temperatures, until at 370° C., although the rate of transformation was still increased by stress, and the bainitic needles were shorter and thicker, their distribution was random.

The general effect on this steel of a compressive stress of 20 tons/sq. in. is to reduce the time required for complete transformation by about one third, and so far as can be judged, to reduce the induction period by about one half.

The first test in the second series of experiments was that carried out on the conical specimen at 280° C., and which has already been recorded. Two other conical specimens, quenched from 800° C. into baths at 250° C. and 240° C. respectively, gave the structures shown in Fig. 15.

More complete tests, under known stresses, were made at 270° C. and 235° C. The first of these, transformed for a standard time of 20 min., included one specimen, the top of which was ground to a cone. The calculated stress on the top surface of the cone

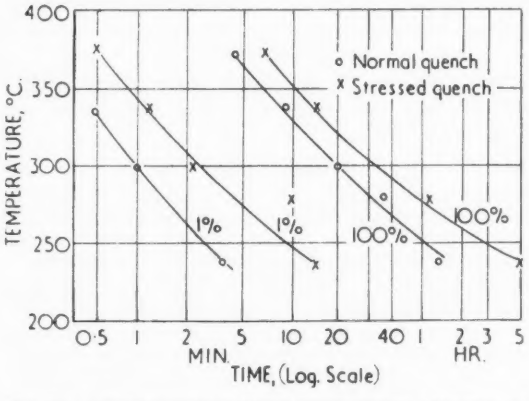


Fig. 20—Transformation/time/temperature diagram of specimen transformed under compressive stress of 20 tons/sq. in.

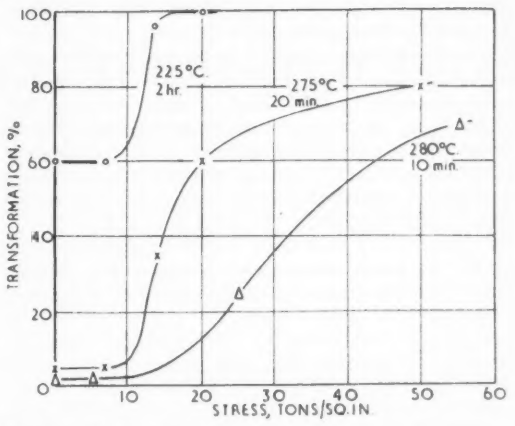


Fig. 21—Curves showing the variation in percentage transformation with imposed compressive stress

was 200 tons/sq. in. This resulted in considerable deformation, reducing the final calculated stress to 50 tons/sq. in. The stress on this specimen was indicated subsequently as 200–250 tons/sq. in. The results of these tests are shown in Figs. 16 and 17.

Comparison of these structures with those produced under normal conditions, Fig. 16*a* and Fig. 17*a* respectively, makes it clear that little, if any, effect is produced by stresses below 10 tons/sq. in., above which a degree of transformation results which increases with increasing stress. This is seen in the curves in Fig. 21, in which the percentage transformation at a given temperature and time is plotted against the imposed stress. The increased rate of transformation is seen to be initiated at about 10 tons/sq. in., a considerable increase in the transformation taking place between 10 and 14 tons/sq. in.

DISCUSSION

Considering the results of the experiments as a whole, it is clear that stress has a considerable effect in increasing the rate of breakdown of austenite, tensile stresses being more effective than compressive, since a tensile stress of 10 tons/sq. in. has the same order of effect as 20 tons/sq. in. in compression. There is no clear evidence, however, that the effects of tensile and compressive stresses are essentially different.

In seeking an explanation, the influence of stress on the distribution of the low-temperature bainite is suggestive. The marked parallelism of the bainite needles in each grain, and the fact that they are inclined at about 45° to the direction of the applied stress, immediately suggests a connection with the deformation by shear. Further, although certain grains showed a considerable degree of transformation, in others this was either small or absent. This fact again is entirely consistent with the view that the breakdown is the result of mechanical stress which must attain a certain critical value to be effective. Those crystals with an octahedral plane at, or near to, 45° to the applied stress will clearly attain the critical shear stress at an earlier stage than in the case of crystals in which no such plane is present.

There is here nothing inconsistent with the view expressed by Thompson and Millington in 1924 that the formation of martensite is the result of mechanical stress sufficient to exceed the elastic limit of the parent austenite.[7] As a result of this twin lamellae should form, involving atomic movement. Such movement, however, in austenite at a temperature at which it is unstable, instead of leading to a twinned orientation, presumably goes on until the stable α-iron lattice results.

If there is any substance in this suggestion there should be some correlation between the elastic properties of the austenite and its thermal stability—the higher the elastic limit, the greater the stress required for breakdown to be initiated. Broadly, this is in accord with fact, the austenite in a plain carbon steel being exceedingly unstable, and that in highly alloyed steels of higher elastic limit being correspondingly more resistant to transformation. It does not appear necessary to suppose that there must necessarily be any strict parallelism between elastic and thermal stability, since there is no evidence that the stresses set up during quenching are the same in all steels. Changes of thermal conductivity, coefficient of contraction, and specific heat are all potential causes of variation in this respect.

The breakdown of austenite to low temperature bainite cannot, according to Mehl,[6] be explained satisfactorily merely on the basis of nucleation and growth, and the discrepancies become increasingly large as the transformation temperature falls. The results of the present experiments suggest that the missing factor in the reaction is the effect of stresses, set up during the quenching, or caused by change within the material.

The evidence at present available suggests that there is nothing inconsistent with the view that the transformation to both martensite and low temperature bainite is initiated by stress. If this stress exceeds the elastic limit of the austenite plastic deformation results, with the ultimate formation of plates of α-iron. If the carbon remains in solution this gives the typical martensitic structure which is dependent, therefore, merely on stress. At somewhat higher temperatures precipitation of carbide ensues, owing to nucleation and subsequent growth. In the production of the bainite, therefore, both shear and nucleation play their parts, the effect of the former being of greater importance at the lower temperatures, where the quenching stresses must inevitably have been higher.

The granular structure and evidence of normal (as distinct from mechanical) twinning, became, as has been stated, clearer as the heat-treatment was prolonged after the completion of the breakdown of the austenite. This fact is significant in emphasizing that even at these temperatures, still further change is proceeding after the first stage of the transformation has occurred. The 'twins' would appear to be pseudomorphic after the corresponding structure of the parent austenite. During the induction period, and under the applied stress of about 20 tons/sq. in., twinning of the austenite is to be expected, the variation of orientation on adjacent sides of the twin boundary then necessarily leading to a corresponding variation of the orientation of the lamellae.

It is almost inconceivable that an ideal undistorted α-iron lattice should be produced in the martensitic lamellae. On all grounds it would appear more probable that a highly imperfect atomic arrangement is set up, and in such a case the possible existence of nuclei, from which subsequent growth can take place, is to be expected. It should be emphasized, however, that this mechanism implies that the production of bainite is caused by a dual change, in the first case to martensite, and subsequently to bainite.

The acceleration of the rate of transformation in the pearlitic range, noted in the tensile experiments, is again presumably because of the imperfection of the austenitic crystals, resulting from the strain, a state of affairs which might be expected to increase the number of nuclei from which precipitation may occur.

CONCLUSIONS

(1) The imposition of stress during transformation increases the rate of austenite decomposition.

(2) Transformation under stress, to low temperature bainite, is marked by certain distributional effects, transformation taking place preferentially on slip or twin bands present in the parent austenite.

(3) Prolongation of the thermal and stress conditions, for a time far in excess of that required for complete transformation, results in a clarification of a granular structure and increased definition of the twin bands. This implies that some further change is taking place.

In order to explain these facts the following tentative suggestions are put forward :

(4) The formation of low temperature bainite is due to the combined action of shear and nucleation, the transformation being initiated by the former and continued owing to the latter. The importance of the two effects varies with the temperature, nucleation being of greater importance at higher temperatures and shear of greater importance at lower temperatures.

(5) The effect of stress in the pearlite range, including transformation to high-temperature bainite, is to produce, by deformation, extra nuclei of α-iron.

Acknowledgments

The authors wish to express their thanks to the British Iron and Steel Research Association for financial assistance.

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The Manufacture of Electric Steel in Great Britain

By the Electric Process Sub-Committee

SYNOPSIS

British electric arc furnace practice is outlined briefly, and complete tabulated data are included for thirty arc furnaces. Practice in one arc furnace shop and in one induction furnace shop is considered in more detail, and reference is made to the use of arc furnaces in foundries.

The processes which have been used for making rimming and balanced mild steel in the electric arc furnace are described, although these classes of steel are not as yet made to any extent in arc furnaces in Great Britain. Among the possible future developments in British electric steelmaking practice, mention is made of the use of oxygen.

Introduction

Because of the relatively high cost of electric power in Great Britain, the percentage of steel made in arc furnaces does not reach the figure attained in some other countries whose resources of water power make relatively cheap electricity available. Nevertheless, the fact that Great Britain is a relatively large producer of steel results in the tonnage of electric steel produced being considerable, in spite of this being a small percentage of the total steel production. This is best illustrated by Table I, which shows the production of electric steel in various countries during the past ten years. From this it will be seen that the second world war resulted in a substantial increase in electric steel production in many countries, although, of course, in others, the effect of enemy occupation is very marked. Owing to reduced requirement for alloy steels, the present output of electric steel is below the peak figures of the war, but there is a substantial permanent increase in interest in the electric process for producing classes of steel of which the price-level would have precluded the use of this process before the war.

At the end of 1947 there were 185 electric furnaces (arc and induction) in Great Britain, of which over half (96) were located in the Sheffield district. The remainder were distributed in the other steelmaking areas, with the exception of the Scunthorpe district of Lincolnshire, in which, although an important area for the production of open-hearth steel, there are no electric furnaces. Availability of hydro-electric power has so far played no part in the location of these plants; in fact, only about 3% of electricity in Britain as a whole is produced from water power. Whilst the hydro-electric resources of the more mountainous parts of the country are now being developed more rapidly, it is doubtful whether this will have any great effect on the existing distribution of electric steelmaking, as these areas are sparsely populated and relatively far from good transport facilities, sources of labour, and the fabricating industries. So far electro-metallurgy based on water-power in Great Britain has tended to be centred on industries requiring electricity for process purposes as well as heating, *e.g.*, the manufacture of aluminium.

Up to the end of the war, electric furnace capacity in Britain was fully occupied in producing alloy and other special steels for which the electric process is specially suited. The end of the war resulted in a certain amount of surplus electric steelmaking capacity and this led to further consideration of possibilities of using electric furnaces for making less expensive steels. This, in turn, led to a closer interest being taken in the cost and economic efficiency of all branches of the process, and to the formation by the British Iron and Steel Research Association of an Electric Process Sub-Committee, the terms of reference of which are "to investigate problems peculiar to the electric steelmaking process." This Sub-Committee held its first meeting on 3rd April, 1946.

Table I

ELECTRIC FURNACE STEEL PRODUCTION IN VARIOUS COUNTRIES

A — Yearly production of electric furnace steel in thousands of tons of 2240 lb.
B — Percentage of electric furnace steel of total production

	U.S.A.		Germany		Japan		Italy		United Kingdom		France		Sweden		Canada		Poland		India		Norway		Hungary	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
1937	846	1·7	..	..	428	7·5	..	..	215	1·7	311	4·0	..	..	103	7·4	36	2·5	1	0·1	..	..	40	6·1
1938	505	1·8	866	3·9	746	11·7	617	27·0	223	2·2	353	5·8	222	23·2	92	7·9	39	2·6	3	0·4	64	100	44	6·9
1939	919	2·0	1102	5·0	876	13·3	697	31·1	292	2·2	565	7·2	289	25·5	109	7·9	..	..	21	2·0	62	100	48	6·7
1940	1518	2·5	1260	6·7	1068	15·8	732	33·0	435	3·4	469	10·8	315	27·9	168	8·4	..	..	34	2·6	..	..	49	6·7
1941	2562	3·5	1485	7·2	1103	17·9	768	37·9	573	4·7	385	9·1	333	29·2	255	10·5	..	..	58	4·2	..	..	59	7·7
1942	3549	4·6	1595	7·9	1398	20·2	760	40·0	860	6·6	354	8·0	339	28·0	404	14·6	..	..	59	4·4	..	..	71	9·2
1943	4097	5·2	1940	9·5	2190	28·5	680	40·0	992	7·6	351	7·0	342	28·6	435	16·2	131	5·4	54	3·9	48	100	74	9·6
1944	3784	4·7	1970	11·0	2740	47·5	525	52·0	795	6·5	238	7·8	345	29·2	411	15·3	151	7·9	65	4·8	35	100	52	10·1
1945	3068	4·3	..	..	450	42·8	..	..	542	4·6	232	14·2	355	30·0	402	15·6	..	..	70	5·3	34	100	7	5·1
1946	2288	3·8	..	..	..	..	..	..	479	3·8	406	9·3	393	32·6	366	17·5	..	..	56	4·4	51	100	17	5·0
1947	3383	4·4	..	..	..	..	600	39·7	576	4·5	448	8·7	380	31·9	382	16·4	..	..	53	4·8	..	..	..	..

Paper SM/AC/19/49 of the Electric Process Sub-Committee of the Steelmaking Division of the British Iron and Steel Research Association, received 16th February, 1949.

The present (March 1949) constitution of the Sub-Committee (including associate members) is as follows :

Dr. J. R. Rait (*Chairman*), Messrs. Hadfields, Ltd.
Mr. F. T. Bagnall, Messrs. Samuel Fox and Sons, Ltd.
Mr. W. H. Bailey, Messrs. Kayser, Ellison and Co., Ltd.
Mr. E. Davies, The Brymbo Steel Co., Ltd.
Mr. W. H. Everard, Messrs. Edgar Allen and Co., Ltd.
Mr. W. L. Harper, Royal Ordnance Factory, Patricroft
Mr. J. C. Howard, The Electric Furnace Co., Ltd.
Mr. R. Lamb, Messrs. Hadfields, Ltd.
Mr. F. V. Lewis, Birlec, Ltd.
Mr. E. Millington, Messrs. Richard Thomas and Baldwins, Ltd.
Mr. J. Mowat, Messrs. Wm. Beardmore and Co., Ltd.
Mr. B. W. Newbould, Messrs. Firth-Brown Steels, Ltd.
Mr. J. Nicol, The Clyde Alloy Steel Co., Ltd.
Mr. R. S. Rolfe, Messrs. Stewarts and Lloyds, Ltd.
Mr. G. A. Wood, English Steel Corporation, Ltd.

Original members who have retired from the Sub-Committee are :

Dr. J. Cameron, The Clyde Alloy Steel Co., Ltd.
Mr. B. G. Davies (*deceased*), Messrs. Richard Thomas and Baldwins, Ltd.
Dr. E. Gregory, Messrs. Edgar Allen and Co., Ltd.
Mr. S. L. Roberton, The Clyde Alloy Steel Co., Ltd.
Mr. C. W. Wright (*deceased*), Messrs. Thos. Firth and John Brown, Ltd.

On B.I.S.R.A. staff the Sub-Committee is served by Mr. R. Toye, in charge of electric furnace research for the Steelmaking Division, of which Dr. A. H. Leckie is the Head and Mr. C. W. J. Crawford is Technical Secretary. Up to the present the Sub-Committee has devoted most of its work to arc furnaces producing ingots, although foundry furnaces and high-frequency induction furnaces also come within its field of activity. Steelmaking problems peculiar to the foundry industry are dealt with by the Melting Sub-Committee (Chairman, Mr. R. Lamb) of the Steel Castings Division of the British Iron and Steel Research Association.

HISTORY

A full history of the early development of electric steelmaking is outside the scope of this paper, and in any case is available in other publications[1, 2] ; however, the main landmarks in the evolution of the process may be summarized as follows :

In 1878 and 1882, Sir William Siemens published descriptions of how he used both direct and indirect arcs for melting small quantities of steel in a crucible. To those who know of Siemens' persistence in developing his open-hearth furnace it is perhaps rather surprising that he did not press the industrial applications of electric arc melting, but it has been suggested that the dynamo, discovered only about ten years previously, was in a very early stage of its development and probably far from trouble-free, so that experiments necessitating a considerable supply of electric power were difficult to perform.

In 1899, Captain Stassano, an Italian, published the results of his work on the use of electric arcs for the reduction of iron ores. At this time the cost of electric power was so high that the possibility of its competing with coke for smelting caused a considerable sensation. Stassano's work was instrumental in drawing the attention of many scientists to the industrial possibilities of electric power for heating.

The most successful of these scientists was the Frenchman, Dr. Paul Heroult, who in 1899 began his extensive experiments on the production of steel from pig iron and steel scrap. He experimented both with bottom electrodes and with hanging electrodes, but for technical reasons he eventually concentrated on the latter, which today is the generally accepted pattern. He was also responsible for developing the tilting furnace, now used universally. The years 1899 to 1903 were years of great progress in electric arc furnace practice. During this period the fundamental metallurgical treatments which are the common basis of present-day arc furnace practice for the production of high-quality steels were discovered and applied industrially in Europe and in the Scandinavian countries.

In Great Britain, during this period, little seems to have been done with arc furnaces, but after the installation of the first Heroult furnace at the works of Messrs. Edgar Allen and Co., Ltd., in 1910, several small furnaces were installed for experimental work on the melting of heavy steel turnings. Early in the first world war the large demand for alloy steels, coupled with the shortage of the high-quality raw materials from which these steels had hitherto been manufactured, gave an impetus to the manufacture of steel in the arc furnace on a commercial scale. The subsequent rapid development of electric furnace capacity is shown in Fig. 1.

The relative advantages and disadvantages of the electric process are well known. In brief, the advantages may be summarized as :

(*a*) Absence of an atmosphere contaminated with undesirable elements such as sulphur. By proper control of the atmosphere the charge can be treated under oxidizing or reducing conditions, permitting a close control of chemical analysis. This results in a cleaner and more uniform steel.

(*b*) Ability to reach very low sulphur and phosphorus contents.

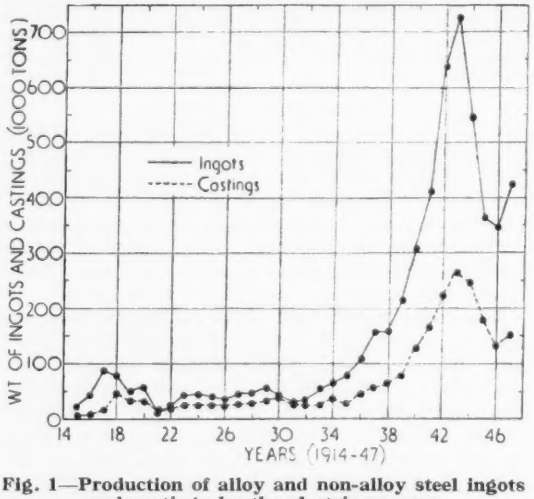


Fig. 1—Production of alloy and non-alloy steel ingots and castings by the electric process

(*c*) Independence of pig iron as a raw material.
(*d*) Better alloy recovery in melting alloy-steel scrap, turnings, etc.
(*e*) Easier control of temperature, and ability to reach high temperatures.
(*f*) Lower capital cost per ton for arc furnaces compared with open hearth.

Had it not been for the existence of the electric furnace, the high-alloy steels required for the manufacture of gas turbines and for other special uses could not have been made.

The only disadvantages are :

(*a*) High cost of power and electrodes. In Britain, typical power costs are approximately 40*s*. per ton* of steel, and electrodes about 16*s*. per ton. These two items can be regarded as fuel cost which, of course, compares unfavourably with the open-hearth fuel costs of about 26*s*. per ton for alloy steels.
(*b*) Limitation of the size of the cast compared with the open hearth, although the ability to melt small charges can, of course, be regarded as an advantage.
(*c*) For certain qualities of forging steel, more careful heat-treatment is required with electric furnace steel than with acid open-hearth steel.

GENERAL DESCRIPTION OF BRITISH ARC FURNACES

Since many of the furnaces in operation in Britain have been working for a considerable number of years, the following description of modern British practice is not characteristic of every works in the country. Nevertheless, it may be considered a picture of modern design tendencies.

Arc furnaces in Britain generally follow the conventional Heroult design, though a number of bottom-electrode furnaces are still in use, particularly in smaller firms. Most firms obtain their furnaces from one or other of the well-known manufacturers so that a detailed description is unnecessary in this paper. Table II gives a summarized description of 30 typical ingot-producing furnaces ; the dimensions *A*, *B*, etc., in the Table are explained in Fig. 2.

Capacity

Unfortunately, no figures are available to show the capacity distribution of the 185 electric steel furnaces in Britain ; nor can Table II be taken as a cross-section in this sense, since data are given for only one arc furnace of each capacity in a particular shop. All that can be deduced from Table II is that the largest furnaces in operation have a capacity of 30 to 35 tons, and that more shops have furnaces in the 10–15 ton range than of any other size. In practice, furnaces tend to be loaded to a capacity well above the nominal.

Mechanical Parts and Shell Construction

All modern electric arc furnaces are now arranged with the electrode-raising gear at the side, the furnace tilting forward for pouring and backwards for slagging. On smaller furnaces there is usually only one door, opposite the pouring spout, but on larger units a second door, opposite the electrode-raising gear, is considered advisable.

Fabricated construction of the shell is common, whilst vulnerable parts, such as door sills and door jambs, are usually made from separate castings for ease of renewal.

Preference is given, in these days of demands on output, to furnaces arranged for top charging, though in larger furnaces there are some advantages of mechanical door charging. Large units may have the gantry-type removable roof or pull-out-body type, or the swing-roof design can be used for both large and small units. Pull-out-body furnaces, where the body is run out on its special bogie, and can be pulled out into an adjacent bay for charging, may be advantageous on some sites.

In Great Britain, comparatively shallow hearths have been favoured, partly because a large slag–metal surface per unit of weight is desirable and partly because of the difficulty of draining a deep hearth with the limited tilting angles available. The Electric Process Sub-Committee is of the opinion that deeper baths than are customary in Great Britain would be of considerable advantage in securing faster and more economical melting. It is hoped that furnace builders will soon be able to overcome the engineering difficulties which may arise when an increased tilting angle is used. The reduced slag–metal interface per ton is not considered to be a serious disadvantage, since the available evidence indicates that the net tons per hour are likely to be higher in spite of an increased time of reaction. In any case, the possibilities of electro-magnetic stirring are being considered to compensate for reduced area of interface.

Several oscillating-hearth furnaces are in operation in Britain. With this system the position of the electrodes, relative to the charge, can be changed during melting down, thus reducing the risk of damage to the furnace hearth. Also, the furnace can be slowly oscillated under automatic control during the refining operation, thereby making the slag more uniform and speeding-up refining. The oscillating-hearth furnace has definite advantages, but whether these advantages outweigh its complications is the subject of much discussion.

Other improvements in details are found on the more modern furnaces, such as simplified door-operating gear and remote control of the electrode clamp tightening gear. A general trend in design is towards the easier and more rapid servicing of the furnace and refractories. An example is the latest type of roof mounting, which permits very simple alignment of the electrode ports, or the rapid replacement of the complete roof. Through improvements in design, water cooling of the more vulnerable parts—once subject to much objection on the part of the

* For comparison with Norwegian costs it can be said that one English shilling per English ton is roughly equivalent to one Norwegian kroner per metric ton.

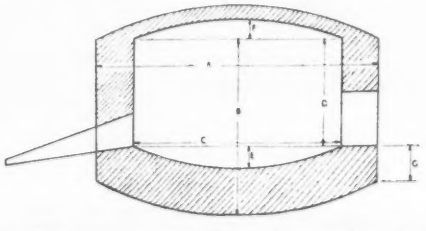


Fig. 2—Key to furnace dimensions referred to in Table II

Table II—DETAILS OF TYPICAL INGOT-PRODUCING ELECTRIC

	No. 1	No. 2	No. 3	No. 4
FURNACE TYPE	3-phase Heroult	3-phase Heroult	Greaves-Etchell	3-phase Heroult
MAKER	Birlec	E.F. Co.		
YEAR	1939	1937	1941	1945
CAPACITY				
Nominal, tons	1·8	2	2	3
Actual, tons	2–2½	2½	2½	3–3½
SHELL DIMENSIONS				
A	5 ft. 3 in.	7 ft. 4 in.	6 ft. 5 in.	7 ft. 10 in.
B	5 ft. 3 in.	7 ft. 8 in.	4 ft. 4 in.	5 ft. 1½ in.
LINING DIMENSIONS				
C	4 ft. 6 in.	5 ft. 0 in.	4 ft. 11 in.	5 ft. 10 in.
D	3 ft. 0 in.	2 ft. 6 in.	1 ft. 9 in.	2 ft. 7½ in.
E	1 ft. 2 in.	1 ft. 5½ in.	1 ft. 0 in.	1 ft. 1 in.
F	4½ in.	6 in.	9 in.	7 in.
SILL LEVEL				
G	2 ft. 6 in.	2 ft. 6 in.	2 ft. 6 in.	2 ft. 6 in.
NO. OF DOORS	2	1	2	2
ANGLE OF TILT				
Tapping	35°	35°	40°	35°
Slagging	Nil	15°	12°	15°
TILTING MECHANISM	Electric rack	Hydraulic	Hydraulic rack	Hydraulic rack
LAUNDER				
Length	3 ft. 3 in.	5 ft. 4 in.	3 ft. 3 in.	6 ft. 7 in.
Angle	10°	4° above horizontal	6° above horizontal	30° above horizontal
PARTS WATER-COOLED	Economisers	Economisers	Economisers	Economisers
BODY TYPE	Fixed	Fixed	Fixed	Fixed
ROOF TYPE	Fixed	Swing	Fixed	Swing
METHOD OF CHARGING	Hand	Basket	Hand	Basket
TRANSFORMER				
Maker	British Electric	Metro-Vickers	British Electric	Metro-Vickers
kVA.	800	1500	700	1500
Max. amp.		4500	6000	
OUTPUT VOLTAGES				
Star	95, 85	110, 84		95, 84, 72
Delta	160, 140	180, 150		165, 145, 125
COOLERS OR ECONOMISERS	6¾ in. bore × 13¾ in. o.d. × 3 in. deep	8½ in. o.d. × 12 in. deep	11 in. o.d. × 5 in. deep	10 in. bore × 14¼ in. o.d. × 2¼ in. deep
ELECTRODES				
Type	Graphite	Graphite	Graphite	Graphite
Maker	British Acheson	British Acheson	British Acheson	British Acheson
Preferred length and dia.	60 in. × 6 in. dia.	60 in. × 8 in. dia.	48 in. × 7 in. dia.	60 in. × 8 in. dia.
Jointing	Screwed nipple	Screwed nipple	Screwed nipple	Screwed nipple
Pitch circle dia.	1 ft. 9½ in.	1 ft. 9½ in.	18 in. (2 electrodes)	2 ft. 0 in.
Consumption/ton chgd., wt.	18·9 lb.	18·9 lb.	16 lb.	18 lb.
Max. current density		80 amp./sq. in.		
ELECTRODE CONTROLLERS				
Maker			E.F. Co.	
Type	Auto and hand	Automatic	Hydraulic	Auto and hand
Year			1942	
TIME FOR:				
Charging	35 min.	5 min.	50 to 60 min.	5 min.
Melting down ('power on' to 'charge molten')	1 hr. 44 min.	1 hr. 45 min.	3 hr.	1 hr. 55 min.
Total time ('power on' to 'off')	3 hr. 28 min.	3½ hr.	5 hr.	4 hr.
CONSUMPTION				
Melting down, kWh./ton	440	440	No meters	450
Refining, kWh./ton	390	390	No meters	400
REFRACTORY AV. LIFE (HEATS)				
Roof	160	238	100	85
Arches	65		50	60
Side-walls	90		50	100
Bottom	1200		700	1200
GENERAL CONSTRUCTION*				
Roof	Silica brick	Silica	Silica	Silica
Arches	Silica brick	Silica	Silica	Silica
Side-walls	Chrome magnesite	Silica	Dolomite bricks	Chrome magnesite
Bottom	Graphitized dolomite	Silica brick and sand	Rammed dolomite	Graphitized dolomite
TYPE OF STEEL MADE				
Carbon and C–Cr	25%		100%	20%
Lower-alloy				
High-alloy	75%			80%
Stainless				
WORKING WEEK	128 hr., three 8-hr. shifts	128 hr., three 8-hr. shifts		128 hr., three 8-hr. shifts

* The terms 'dolofer' and 'dolomex' are trade names for stabilized dolomite bricks; '341' is a semi-stable dolomite brick.

ARC FURNACES (For an explanation of the dimensions *A*, *B*, etc., see Fig. 2)

No. 5	No. 6	No. 7	No. 8	No. 9	No. 10
3-phase Heroult	Greaves-Etchell	3-phase Heroult	3-phase Heroult	3-phase Heroult	3-phase Heroult
E.F. Co.	Edgar Allen (Furnace designed by S. & J.)	Siemens-Schuckert		E.F. Co.	Stobie (modified)
1944	1942	1935-36	1940	1939	
3½ Up to 4½	4½ 5	5 5	5 6½	5 7	10 10
8 ft. 0 in. 5 ft. 0 in.	9 ft. 4½ in. 5 ft. 0⅞ in.	9 ft. 2½ in. 5 ft. 9½ in.	9 ft. 5½ in. 5 ft. 8 in.	9 ft. 6 in. 5 ft. 8 in.	10 ft. 6 in. 6 ft. 4 in.
5 ft. 9 in. 3 ft. 9½ in. 1 ft. 8 in. 5½ in.	7 ft. 4½ in. 2 ft. 6 in. 1 ft. 2 in. 10 in.	6 ft. 4½ in. 2 ft. 10½ in. 1 ft. 6 in. 5½ in.	7 ft. 1½ in. 2 ft. 10 in. 1 ft. 3 in. 8 in.	7 ft. 1¼ in. 2 ft. 7 in. 2 ft. 0 in. 8 in.	9 ft. 0 in. 2 ft. 7½ in. 1 ft. 9 in. 11½ in.
2 ft. 2 in.	2 ft. 6 in.	2 ft. 9 in.	2 ft. 3 in.	1 ft. 7½ in.	2 ft. 1½ in.
2 (side)	3	1	2	1 (slagging)	2
33° 12°	60° 25°	40° (approx.) 20°	35° 15°	40° 15°	45° 7°
Electric screw	Electric rack	Electric rack	Electric rack	Hydraulic rack	Electric rack
3 ft. from shell 5°	3 ft. 0 in. 5° above horizontal	4 ft. 10 in. 12°	7 ft. 0 in. 15° and 5° from horizontal	7 ft. 0 in. 5°	4 ft. 10 in. 73°
None	Economisers	Arch, tap-hole arch, economisers	Economisers	Door arch, tap-hole arch, economisers	Economisers
Fixed	Fixed	Fixed	Fixed	Lifting and swinging	Fixed
Fixed	Fixed	Fixed	Fixed	Travelling	Fixed
Hand	Hand	Hand	Hand	Basket	Hand
Metro-Vickers 1500 5250	British Electric 850 7000	Siemens-Schuckert 1500	Metro-Vickers 2300 5000	Metro-Vickers 2300 7380	Metro-Vickers 416 (each phase) 7000
95, 84, 72 165, 145, 125			114, 95, 85 180, 160, 140	114, 100, 85 180, 160, 140	92, 80, 69 160, 140, 120
10¾ in. bore × 14¼ in. o.d. × 4 in. deep	1 ft. 4 in. o.d. × 5 in. deep	10½ in. bore × 14 in. o.d. × 12⅝ in. deep	15½ in. bore × 22½ in. o.d. × 9 in. deep	16 in. o.d. × 9 in. deep	14¼ in. o.d. × 12 in. deep
Graphite British Acheson 60 in. × 10 in. dia. Screwed nipple 2 ft. 4 in. 12·8 lb. 55 amp./sq. in.	Graphite British Acheson 60 in. × 8 in. dia. Screwed nipple 27 in. (2 electrodes) 17 lb.	Graphite British Acheson 60 in. × 9 in. dia. Screwed nipple 2 ft. 8 in. 14·5 lb.	Amorphous British Acheson 60 in. × 14 in. dia. Screwed nipple 2 ft. 8 in. 35 lb.	Graphite British Acheson 60 in. × 9 in. dia. Screwed nipple 2 ft. 10 in. 16 lb. 95 amp. sq. in.	Graphite British Acheson 60 in. × 8 in. dia. Screwed nipple 2 ft. 6 in. 8·9 lb. 140 amp./sq. in.
Watford 1944	E.F. Co. Hydraulic 1942	Siemens-Schuckert	Auto and hand	E.F. Co. Atmas regulator elec.-hydrl. 1939	Auto-electric
37 min.	50-60 min.	1 hr.	45 min.	15 min.	1 hr. 40 min.
2 hr. 37 min. 4 hr. 35 min.	4 hr. 6 hr.	2½ hr. 3 hr.	2 hr. 30 min. 4 hr. 15 min.	2½ hr. 7 hr.	2¼ hr. 4 hr. 50 min.
741	(No meters)	500 300	590 140	607 228	396 267
84 63 84 2000	200 60 100 1500	200 70 70 800-1200	80 65 120 450	60 40 60 600	60 20 40 2200 (approx.)
9 in. silica, 12 in. round coolers Silica Dolomite Graphitized dolomite	Silica Silica Silica Rammed dolomite	Silica Door silica, tap-hole spinella Silica above slag, spinella below Insulation course, then rammed dolomite	Silica brick Silica brick Chrome magnesite Dolofer and magnesite next to shell, rammed dolomite lining	Silica brick in fabricated steel ring Silica brick Silica Rammed dolomite, magnesite next shell	Silica Firebrick Silica Rammed dolomite
10% 15% 70% 5%	100%		2% 98%	75% 15% 10% None	} Main production A little only
128 hr., three 8-hr. shifts	44 hr., 1 shift	136 hr., three 8-hr. shifts	128 hr., three 8-hr. shifts	168 hr. continuous	124 hr., three 8-hr. shifts

Table II (*continued*)—**DETAILS OF TYPICAL INGOT-PRODUCING ELECTRIC**

	No. 11	No. 12	No. 13	No. 14
FURNACE TYPE	Heroult	3-phase Heroult	3-phase Heroult, rotating hearth	3-phase Heroult, rotating hearth
MAKER	Siemens-Schuckert	E.F. Co.	E.F. Co.	Siemens-Schuckert
YEAR	1936	1944	1941	1939
CAPACITY				
Nominal, tons	8	8–10	10	10
Actual, tons	9½	12	12½	10·8
SHELL DIMENSIONS				
A	10 ft. 10 in.	11 ft. 6 in.	12 ft. 6 in.	12 ft. 6 in.
B	6 ft. 2 in.	6 ft. 6 in.	7 ft. 1 in.	7 ft. 0 in.
LINING DIMENSIONS				
C	7 ft. 8 in.	9 ft. 0 in.	8 ft. 11 in.	8 ft. 10½ in.
D	2 ft. 6 in.	2 ft. 8 in.	3 ft. 8 in.	3 ft. 7 in.
E	1 ft. 9 in.	21½ in.	1 ft. 5½ in.	1 ft. 7 in.
F	5½ in.	11 in.	1 ft. 1 in.	11¾ in.
SILL LEVEL				
G	2 ft. 1 in.	2 ft. 6 in.	2 ft. 1 in.	2 ft. 4 in.
NO. OF DOORS	2 (working) 1 (tapping and slagging)	2	2 (tap and slag)	2 (tap and slag)
ANGLE OF TILT				
Tapping	40°	40°	38°	38°
Slagging		15°	20° max.	15°
TILTING MECHANISM	Electric screw	Hydraulic	Electric screw	Electric screw
LAUNDER				
Length	2 ft. 0 in.	8 ft. 3 in.		
Angle		4° above horizontal	5°	6°
PARTS WATER-COOLED	Economisers	Arch, tap-hole arch, economisers	Arch, roof ring, economisers	Arch, tap-hole arch (outside casing), roof ring, economisers
BODY TYPE	Fixed	Swing hydraulic	Fixed	Fixed
ROOF TYPE	Fixed	Fixed	Sliding and rotating	Sliding and rotating
METHOD OF CHARGING	Hand	Basket	Basket	Basket
TRANSFORMER				
Maker	B.T.H.	Metro-Vickers	English Electric	English Electric
kVA.	4000	3500	3500	3500
Max. amp.	15,000	9500	9200	9200
OUTPUT VOLTAGES				
Star	100, 95, 90, 85, 80, 75	112, 90, 70	127, 115, 104, 95	127, 115, 104, 93
Delta	173, 164, 155, 147, 138, 130	190, 150, 120	220, 200, 180, 160	220, 200, 180, 160
COOLERS OR ECONOMISERS	31 in. o.d., 21 in. i.d., + brick segment to 20 in., × 4 in. deep	12¼ in. o.d., ring type	13½ in. bore × 23 in. o.d. × 15 in. deep	13½ in. bore × 21 in. o.d. × 15 in. deep
ELECTRODES				
Type	Amorphous	Graphite	Graphite	Graphite
Maker	British Acheson	British Acheson	British Acheson	British Acheson
Preferred length and dia.	60 in. × 20 in. dia.	60 in. × 14 in. dia.	72 in. × 12 in. dia.	72 in. × 12 in. dia.
Jointing	Screwed nipple	Screwed nipple	Screwed nipple	Screwed nipple
Pitch circle dia.	20 in.	3 ft. 4½ in.	3 ft. 9 in.	3 ft. 9¼ in.
Consumption/ton chgd., wt.	42 lb.	18 lb.	15 lb.	13 lb.
Max. current density	45 amp./sq. in.	60 amp./sq. in.	80 amp./sq. in.	80 amp. sq. in.
ELECTRODE CONTROLLERS				
Maker	Watford Elec.	Hydraulic	Watford	Siemens Automatic
Type				
Year	1946		1941	1939
TIME FOR :				
Charging	1 hr. 15 min. (charging and fettling)	20 min.	5–10 min.	5–10 min.
Melting down ('power on' to 'charge molten')	2 hr. 10 min.	4 hr. 15 min.	2¾ hr.	2¾ hr.
Total time ('power on' to 'off')	5 hr. 40 min.	8 hr. 20 min.	5¾ hr	5¾ hr.
CONSUMPTION				
Melting down, kWh. ton	520	665	550	530
Refining, kWh./ton	330	165	300	300
REFRACTORY AV. LIFE (HEATS)				
Roof	54	75	160	160
Arches	Charging arches 3 wks., tpg. arches 3 wks.	28–42	80–90	80–90
Side-walls	3 wks. (quick repair every 3 wks.)	182–196	80–90	80–90
Bottom	Up to 9 mnth., approx. 550	800	1000	1000
GENERAL CONSTRUCTION*				
Roof	12 in. silica	Silica brick	Silica brick	Silica
Arches	Silica	Silica brick	Silica brick	Silica
Side-walls	'341'	Silica brick	'341'	'341'
Bottom	Rammed dolomite	Graphitized dolomite	Insulation course, dolofer, rammed dolomite, tar	Insulation course, dolofer, rammed dolomite, tar
TYPE OF STEEL MADE				
Carbon and C–Cr	All classes	5%		
Lower-alloy		5%		
High-alloy				
Stainless		90%	Few casts per year	A few casts only
WORKING WEEK	128 hr. (melting), three 8-hr. shifts	128 hr., three 8-hr. shifts	142 hr., 8-hr. shifts	142 hr., 8-hr. shifts

* The terms 'dolofer' and 'dolomex' are trade names for stabilized dolomite bricks; '341' is a semi-stable dolomite brick.

No. 15	No. 16	No. 17	No. 18	No. 19	No. 20
3-phase Heroult	3-phase Heroult	Heroult	3-phase Heroult	3-phase Heroult	Greaves-Etchell
E.F. Co.	Siemens-Schuckert	Siemens-Schuckert	E.F. Co.	E.F. Co.	P. Adamson and Co.
1940	1939	1934	1936–41	1938	1917
10	10	10	10	10	12
8–12	12	12	12½	13½	10
11 ft. 6 in.	12 ft. 5⅛ in.	11 ft. 9⅜ in.	12 ft. 6 in.	12 ft. 6 in.	11 ft. 2 in.
7 ft. 2 in.	7 ft. 1⅞ in.	6 ft. 6 in.	6 ft. 9 in.	6 ft. 8 in.	6 ft. 4½ in.
9 ft. 11 in.	9 ft. 4¾ in.	7 ft. 10½ in.	9 ft. 6 in.	10 ft. 2 in.	9 ft. 8 in.
3 ft. 3 in.	3 ft. 10⅝ in.	2 ft. 11½ in.	3 ft. 0 in.	3 ft. 9 in.	2 ft. 5 in.
2 ft. 2 in.	1 ft. 5⅞ in.	1 ft. 8 in.	2 ft. 0 in.	2 ft. 0 in.	1 ft. 8 in.
10½ in.	5⅞ in.	7⅞ in.	11 in.	9 in.	11 in.
2 ft. 6 in.	2 ft. 4 in.	2 ft. 3½ in.	2 ft. 6 in.	2 ft. 7 in. with brick, 2 ft. 4 in. to plate	2 ft. 5 in.
1	1	1 (working) 1 (tapping	2	3	3
40° 15°	42° 15°	40° 20°	35° 15°	35 15	30 None
Electric rack roller	Electric rack	Electric roller	Electric	Electric rack	Electric screw
6 ft. 6 in. 5°	6 ft. 3 in. (approx.) 12°	9 ft. 4 in. 3°	7 ft. 7 in. 6° above horizontal	10 ft. 9 in. 5°	4 ft. 0 in. 6°
Economisers	Arch, tap-hole arch, economisers	Economisers	Economisers	Economisers	Economisers
Swing	Fixed	Sliding	Fixed	Fixed	Fixed
Fixed	Sliding	Fixed	Fixed	Fixed	Fixed
Machine	Basket	Basket	Machine	Scoop	Hand
Metro-Vickers 3000 9630	English Electric 3500 9200	English Electric 3750 12,000	Metro-Vickers 3500 12,000	Hackbridge 3500 1100	British Electric 2600
106, 94, 81	127, 115, 104, 93	127, 115·5, 104, 95·5, 83·8	120, 108, 95, 82	115, 103, 92, 81	
180, 160, 140	220, 200, 180, 160	220, 200, 180, 165, 145	200, 182, 160, 140	200, 180, 160, 140,	
20½ in. o.d. × 9 in. deep	16 in. bore × 24 in. o.d. × 9 in. deep	22 in. o.d., 14½ in. i.d. + segment to 12 in. × 31 in. deep	21 in. o.d. (amor.) or 14½ in. o.d. (graph.) × 2 ft. 6 in. deep	21 in. o.d. × 9 in. deep	11 in. bore × 18 in. o.d. × 5 in. deep
Graphite	Graphite	Graphite	Graphite and amorphous	Amorphous	Graphite
British Acheson 60 in. × 12 in. dia.	British Acheson 60 in. × 14 in. dia.	British Acheson 60 in. × 12 in. dia.	British Acheson 60 in. × 14 in. dia. (graph.) or 20 in. dia. (amor.)	British Acheson 60 in. × 20 in. dia.	British Acheson 60 in. × 10 in. dia.
Screwed nipple 3 ft. 3 in. 20 lb.	Screwed nipple 3 ft. 4 in. 18 lb.	Screwed nipple 22 in. 17 lb.	Screwed nipple 3 ft. 4 in. 20–21 lb. (graph.). 34·2 lb. (amor.)	Screw and paste 3 ft. 3 in. 40 lb.	Screwed nipple 4 ft. 8 in. (4 electrodes) 16 lb.
86 amp./sq. in.	60 amp./sq. in.	120 amp. sq. in.	70 amp./sq. in. (graph.)	35 amp./sq. in.	
Armas E.F. Co. Electric hydraulic 1940	Watford Automatic 1939	Siemens-Schuckert Electrical 1934	Rotary 1947	Watford Automatic 1938	Watford
1¼ hr.	5–10 min.	30 min. (charging and fettling)	20 min.	70 min.	1 hr.
3 hr.	2½ hr.	2 hr. 15 min.	4 hr. 15 min.	2½ hr.	3 hr. 30 min.
5¼ hr.		5 hr. 40 min.	8 hr. 20 min.	6½ hr.	6 hr. 20 min.
610 280	495 415	510 300	665 165	490–510 250	540 230
36 36	100 60	54 Working door 2 wks., tapping door 3 wks.	90 (graph.), 75 (amor.) 28–42	42 30	40–50 40–50
150	60–80 with local patching	3 wks. (quick rep. every 3 wks.)	182–196	42	40–50
271	800–1200	Up to 9 mnths. App. 550	800	340	Up to 1000
Domed silica Segment silica	Silica Door, silica; tap-hole spinella	12 in. silica Silica	Silica brick Silica brick	9 in. silica squares Silica	Spring arch: SiO_2 brick Silica brick
Circ. chrome mag.	SiO_2 above slag, spinella below	'341'	Chrome magnesite	14 in. silica squares and crowns	Silica brick
Rammed dolomite	Graphitized dolomite	Rammed dolomite	Graphitized dolomite	Rammed dolomite, dolofer, and magnesite bricks	Rammed dolomite, spiked
60% 10% 30% Nil	10% 65% 15%	All classes	5% 5% 90%	70% 30% Occasional Occasional	All classes
147 hr., three 8-hr. shifts	136 hr., three 8-hr. shifts	128 hr. (melting), three 8-hr. shifts	128 hr., three 8-hr. shifts	128 hr., three shifts	128 hr., three 8-hr. shifts, Sun. 10 p.m. to Sat. 6 a.m.

Table II (*continued*)—DETAILS OF TYPICAL INGOT-PRODUCING ELECTRIC

	No. 21	No. 22	No. 23	No. 24
FURNACE TYPE	3-phase Heroult	Heroult	3-phase Heroult	3-phase Heroult
MAKER	E.F. Co.	Siemens-Schuckert	Siemens-Schuckert	E.F. Co.
YEAR	1941	1932	1942	1940
CAPACITY				
Nominal, tons	12	12	15	15
Actual, tons	14	15	18	15–20
SHELL DIMENSIONS				
A	12 ft. 6 in.	12 ft. 6 in.	14 ft. 0 in.	14 ft. 0 in.
B	6 ft. 8 in.	6 ft. 6 in.	7 ft. 4⅜ in.	7 ft. 2 in.
LINING DIMENSIONS				
C	10 ft. 6 in.	8 ft. 6⅜ in.		12 ft. 3 in.
D	2 ft. 11 in.	2 ft. 11½ in.	3 ft. 11¾ in.	3 ft. 4 in.
E	1 ft. 11 in.	1 ft. 9 in.	1 ft. 7¾ in.	2 ft. 0 in.
F	12½ in.	7 in.	7½ in.	10 in.
SILL LEVEL				
G	2 ft. 3 in.	2 ft. 3½ in.	2 ft. 4¼ in.	2 ft. 6 in.
NO. OF DOORS	2	1 (working) 1 (tapping)	1	2 (only one used)
ANGLE OF TILT				
Tapping	35°	40°	40°	40°
Slagging	15° (backward)	20°	15°	15°
TILTING MECHANISM	Electric roller	Electric roller	Electric rack	Electric rack roller
LAUNDER				
Length	12 ft.	7 ft. 0 in.	9 ft. 6 in.	8 ft. 6 in.
Angle	5°	4½°	10°	5°
PARTS WATER-COOLED	Roof ring, economisers	Economisers	Door arch and tap-hole arch	Economisers
BODY TYPE	Fixed	Sliding	Lifting	Fixed
ROOF TYPE	Fixed	Fixed	Travelling	Fixed
METHOD OF CHARGING	2-ton Wellman skip charger	Basket	Basket	Machine
TRANSFORMER				
Maker	Metro-Vickers	B.T.H.	English Electric	Metro-Vickers
kVA.	3500	3500	7909	4500
Max. amp.	20,000	15,000	15,750	14,750
OUTPUT VOLTAGES				
Star	118, 106, 94, 81	121, 113, 104, 95·3, 89·5, 84	153, 144, 117, 100, 92·5	115, 102, 90, 80
Delta	200, 188, 160, 140	210, 195, 180, 165, 155, 145	220, 200, 180, 160, 150	200, 176, 156, 140
COOLERS OR ECONOMISERS	1 ft. 10½ in. o.d. × 7 in. deep	24 in. o.d., 15 in. i.d., segment to 14 in., × 20 in. deep	2 ft. 0 in. o.d. × 2 ft. 2 in. deep	22 in. o.d. × 14¼ in. deep
ELECTRODES				
Type	Graphite	Graphite	Graphite	Graphite
Maker	British Acheson	British Acheson	British Acheson	British Acheson
Preferred length and dia.	60 in. × 14 in. dia.	60 in. × 14 in. dia.	71 in. × 14 in. dia.	60 in. × 14 in. dia.
Jointing	Screwed nipple	Screwed nipple	Screwed nipple	Screwed nipple
Pitch circle dia.	4 ft.	24½ in.	4 ft. 6 in.	4 ft. 0 in.
Consumption/ton chgd., wt.	18 lb.	15 lb.	16 lb.	20 lb.
Max. current density	75 amp./sq. in.	95 amp./sq. in.	85 amp./sq. in.	80 amp./sq. in.
ELECTRODE CONTROLLERS				
Maker	Watford	Watford	Watford	Watford
Type	Auto contactor	Electrical	Balanced-power type	Electric E.F.I.
Year	Installed 1941	1945	1942	1940
TIME FOR :				
Charging	20 min.	15 min.	5 min.	1½ hr.
Melting down ('power on' to 'charge molten')	2½ hr.	2 hr. 45 min.	2½ hr.	3 hr.
Total time 'power on' to 'off'	6½ hr.; 10 min. slagging	6 hr. 30 min.	7 hr. 20 min. slagging	6¼ hr.
CONSUMPTION				
Melting down, kWh./ton	520	500	555	560
Refining, kWh./ton	230	250	166	330
REFRACTORY AV. LIFE (HEATS)				
Roof	105	54	60	36
Arches	80	Wkg. dr. 2 wks., tapg. dr. 3 wks.	40	36
Side-walls	105	3 wks. (quick rep. every 3 wks.)	60	150
Bottom	600	Up to 9 months, approx. 550	500	271
GENERAL CONSTRUCTION*				
Roof	Silica brick	12 in. silica	Silica brick in steel ring	Domed silica
Arches	Silica brick	Wkg. dr. SiO_2, tpg. dr. '341'	Silica brick	Segment silica
Side-walls	Chrome magnesite (2 courses), magnesite above slag line	'341'	Silica and magnesite	Circular chrome mag.
Bottom	Rammed dolomite	Rammed dolomite on '341' on dolomex	Rammed dolomite, dolofer brick, firebrick and insulating brick	Rammed dolomite
TYPE OF STEEL MADE				
Carbon and C-Cr	30%	All classes	75%	70%
Lower-alloy	50%		15%	5%
High-alloy	10%		10%	25%
Stainless	10%		None	Nil
WORKING WEEK	128 hr., three 8-hr. shifts	128 hr. (melting), three 8-hr. shifts		147 hr. three 8-hr. shifts

* The terms 'dolofer' and 'dolomex' are trade names for stabilized dolomite bricks; '341' is a semi-stable dolomite brick.

No. 25	No. 26	No. 27	No. 28	No. 29	No. 30
3-phase Heroult	3-phase Heroult, rotating hearth	Heroult	Heroult	3-phase Heroult	3-phase Heroult
E.F. Co.	E.F. Co.	Siemens-Shuckert		Tagliaferri Metallectric	E.F. Co.
1939	1941	1929	1946	1939	1935, rebuilt 1946
15 15–20	20 20	20 25	20 27	25 27½	30 33
14 ft. 0 in. 6 ft. 10 in.	15 ft. 0 in. 7 ft. 8 in.	15 ft. 5 in. 7 ft. 9 in.	16 ft. 0 in. 7 ft. 8 in.	15 ft. 0 in. 8 ft. 4 in.	16 ft. inside casing 7 ft. 11 in.
12 ft. 6 in. 3 ft. 1 in. 2 ft. 0 in. 1 ft. 1 in.	10 ft. 0 in. 3 ft. 7 in. 2 ft. 3 in. 1 ft. 2 in.	10 ft. 10 in. 3 ft. 2½ in. 2 ft. 1½ in. 14⅞ in.	10 ft. 2½ in. 3 ft. 2½ in. 2 ft. 0 in. 14¾ in.	11 ft. 8 in. 4 ft. 0 in. 2 ft. 3 in. 7½ in. normal; 15 in. standard roof	13 ft. 0 in. 3 ft. 9½ in. 2 ft. 3 in. to 2 ft. 6 in. 1 ft. 1½ in.
2 ft. 1½ in.	1 ft. 10 in.	2 ft. 5½ in.	2 ft. 1 in.	24 in.	2 ft. 6 in.
2 (only one used)	1	1 (working) 1 (tapping)	1 (working) 1 (tapping)	1	3
40° 15°	35° 15°	40° 20°	42° 20°	35° 15°	35° 15°
Electric rack	Electric rack	Electric roller	Electric roller	Hydraulic	Electric
7 ft. 0 in. 5°	12 ft. 0 in. 5°	4 ft. 10 in. 4°	8 ft. 10 in. 3°	6 ft. 0 in. 16°	7 ft. 10 in. 6° above horizontal
Economisers	Doors	Door arch, tap-hole arch, economisers	Economisers	Doors, roof ring and bus bars, and economisers	Economisers
Fixed	Lifting	Fixed	Fixed	Vertical lift	Fixed
Fixed	Sliding and rotating	Fixed	Sliding	Sliding	Fixed
Machine	Basket	Machine	Basket	Basket	Machine
	English Electric	Siemens-Schuckert	B.T.H.	B.T.H.	Metro-Vickers
4500 13,000	6000 15,750	5400 17,000	6000 19,000	7500 19,700	6000 19,000
130, 117, 104, 92 225, 203, 180, 158	137, 122, 109, 94·5, 84 220, 198, 180, 157, 140	104, 95 180, 165	156, 142, 128, 114, 90, 83 270,245,221,196,156,145	118, 105, 92, 82 220, 196, 175, 156	117, 102, 90, 82 200, 176, 156, 140
19 in. o.d. × 8¾ in. deep	2 ft. 0 in. o.d. × 5½ in. deep	22 in. o.d., 15½ in. i.d., + seg. to 14 in. dia., × 20 in. deep	27 in. o.d., 18 in. i.d., + seg. to 16 in. dia., × 23 in. deep	16⅜ in. bore × 25½ in. o.d. × 10 in. deep	17 in. i.d. × 14¼ in. deep
Graphite British Acheson 60 in. × 14 in. dia. Screwed nipple 3 ft. 8 in. 14 lb. 80 amp./sq. in.	Graphite British Acheson 72 in. × 16 in. dia. Screwed nipple 4 ft. 4 in. 20 lb. 80 amp./sq. in.	Graphite British Acheson 60 in. × 14 in. dia. Screwed nipple 28 in. 13 lb. 110 amp./sq. in.	Graphite British Acheson 72 in. × 16 in. dia. Screwed nipple 28½ in. 14 lb. 90 amp./sq. in.	Graphite British Acheson 60 in. × 16 in. dia. Screwed nipple 3 ft. 10½ in. 16 lb. 80 amp./sq. in.	Graphite British Acheson 60 in. × 16 in. dia. Screwed nipple 4 ft. 2 in. 21 lb. 90 amp./sq. in.
Watford Contactor 1940	Watford Automatic 1941	Watford Electrical 1946	Watford Electrical 1946	Tagliaferri Hydraulic Installed 1939	Automatic
1¼ hr.	10–15 min.	1 hr. 15 min.	15 min.	5 min.	30 min.
3½ hr. 5½ hr., alloy steels 7¼ hr.	3–3½ hr. 6½ hr.	3 hr. 15 min. 6 hr. 45 min.	2 hr. 40 min. 6 hr. 50 min.	2¾ hr. 5 hr.	5 hr. 30 min. 10 hr.
594 114	550 250	510 215	520 230	470 200	576 185
112 35	80 60	50 3 wks.	48 Working door, 2 wks. SiO_2	35–40 50	110 30
150	60	4 wks. (quick repair every 3 wks.)	Tapping door, 3 wks.	90	50–60
500	1000	Up to 12 months 600	3 wks. (quick repair every 3 wks.) Up to 12 mth., approx. 550	1000	550
9 in. thick silica or mullite	12 in. silica dome	12 in. silica	12 in. silica	12 in. silica brick—15 in. rise	Silica brick
Chrome mag. with silica insulation	SiO_2 segment (chrg. dr)	Working door silica	Working door silica	Rammed dolomite and tar	Silica brick
9 in. basic '341'	Mag. segment (tappg.) Chrome magnesite	Tapping door '341' '341'	Tapping door '341' '341'	Rammed dolomite and tar	Silica brick
Rammed dolomite	Rammed dolomite	Rammed dolomite on '341' on dolomex	Dolomite on '341' on dolomex	Rammed dolomite and tar	Graphitized dolomite
100% low carbon	70% 30%	All classes	All classes	95% 5%	30% 68% 2%
147 hr., three 8-hr. shifts	143 hr., three 8-hr. shifts	128 hr. (melting), three 8-hr. shifts	128 hr. (melting), three 8-hr. shifts	144 hr., three 8-hr. shifts	128 hr., three 8-hr. shifts

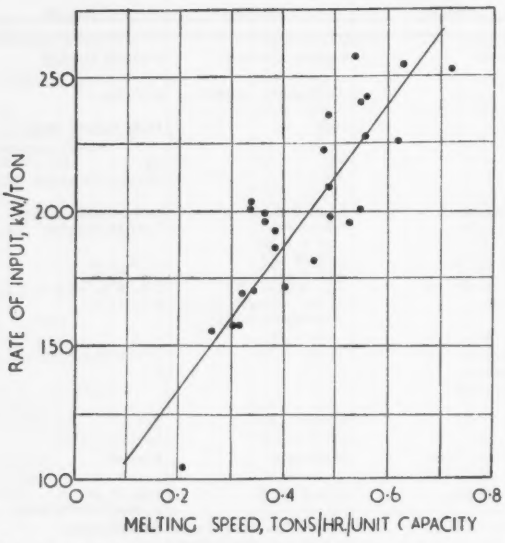


Fig. 3—Relation between rate of power input and speed of melting in arc furnaces

user, on account of increased maintenance—is now much more readily accepted for furnace doors, door jambs, door arches, and roof rings.

Electrical Equipment

The modern arc-furnace transformer, specially designed for its purpose, is a very robust and reliable unit. Practically without exception, the three phases are delta-connected on the secondary side. A wide range of arc voltages is made available by tappings on the primary winding, and it is normal to arrange for alternative star or delta connection of the primary, thus doubling the number of low-tension voltages.

At present, off-load tap-change gear is preferred. The tap switch is fully interlocked with the circuit breaker to prevent on-load operation. The extra cost and complication of on-load tap-change gear has, so far, not been considered worth while. Transformers are oil-immersed, and there are examples of natural, forced-air, and forced-water cooling. Water cooling has much to commend it in a congested and dirty site.

All early electric furnaces had, of course, oil-circuit breakers, and many firms still prefer them on new installations, especially for voltages of 11 kV. and less. The chief item of maintenance is replacement or reconditioning of the switch oil, made necessary by breaking a circuit on load. A special control system has been developed which eliminates switching-off on load, except in cases of emergency.

In addition, to reduce the frequency of circuit-breaker operation, two-stage overload protection may be used, employing two relays, one with a long-delay low over-current setting to take care of normal furnace overloads, and the other with short-delay high over-current setting to take care of transformer and switch faults. Air-break switchgear has been considered as an alternative to the oil-circuit breaker and avoids oil maintenance. The air-blast circuit breaker is one example, while the more recently developed high-voltage contactor is now being used at voltages up to 11 kV.

An important factor in any furnace installation is the ability of its electrode regulator to maintain a good load factor without high peaks of power. By avoiding high power peaks, it is permissible to reduce circuit reactance and so to increase the power factor. An important modern development is the rotary regulator which comprises, essentially, a motor-generator set with special, separate generators to supply power to each of the three electrode control motors. The field current of each generator is controlled through rectifiers from current and potential transformers on the conductors of the appropriate electrode. Thus, the generator output is adjusted instantaneously to control the direction and speed of rotation of the electrode motor so as to maintain the desired arc condition. In addition to giving improved regulation, the rotary regulator required minimum maintenance on account of the absence of contactors and relays. The satisfactory results obtained from these regulators are encouraging many British operators to change to this type as soon as an opportunity arises.

At present, the maximum operating voltages, as is seen from Table II, vary from 160 V. in the smaller furnaces to 225 V. in the larger furnaces. One new furnace has a maximum figure of 270 V., which shows that the tendency in new installations is to increase the secondary voltages.

Figure 3 shows the data analysed to give the connection between power input and rate of steelmaking, and shows the expected relationship. Transformer capacity is examined in Fig. 4, and shows that, in general, British furnaces operate with smaller transformer capacity than those in America. There is a temptation to suggest that an increase in transformer capacity would be advantageous, but at least one British plant is obtaining excellent operating figures from transformers running substantially above their nominal rating.

Electrodes

Most British furnaces use graphite electrodes, although amorphous carbon electrodes are sometimes used. Owing to the high cost of electrodes, increasing interest is being shown in the self-coking (Söderberg) type, and experience with these electrodes in Norway and Sweden is being followed with interest.

Figure 5 shows the data of Table II plotted as a relation between current density and electrode consumption, suggesting that a high current density gives low electrode consumption. This agrees with the

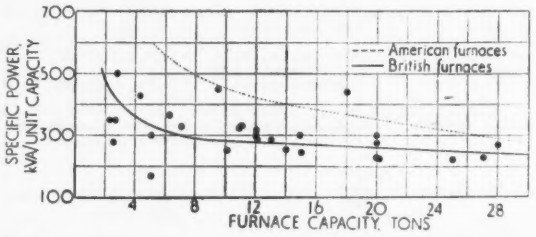


Fig. 4—Comparison between specific transformer power of British and American furnaces

findings of Jernkontoret.[3*] It remains to be seen whether high current densities can be used without detriment to steel quality. The maximum and minimum current densities for various electrode sizes recommended by the manufacturers are given in Fig. 6. Comparison with the data of Table II shows that graphite electrodes in Great Britain are rather large for the input currents used, and might advantageously be reduced. Tests are now being carried out to investigate whether any savings can be achieved by this means. It is worth pointing out, in this connection, that furnace No. 11, shown in Table II to have the remarkably low electrode consumption figure of 8 lb./ton, has particularly small electrodes—8 in. in dia., compared with the more usual 12 to 14 in. for this size of furnace.

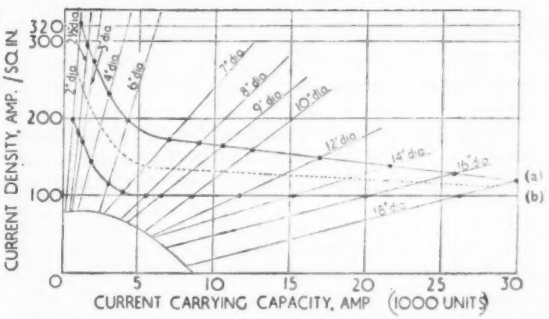


Fig. 6—Current-carrying capacity of graphite electrodes (taken from makers' specifications); (*a*) maximum, (*b*) minimum

Charging Methods

The three methods of charging in general use, *viz.*, hand, basket, and machine, are used on small, medium, and large furnaces respectively. Theoretically, of course, the system enabling the charge to be put into the furnace in the shortest possible time, so minimizing the loss of stored heat, is the best, and in this respect, basket charging appears to be the ideal method. When the scrap is of ideal shape and size, the whole charge can be put into the furnace with one roof removal, but in a few works, where the charge consists mainly of turnings or light scrap, making several removals of the roof necessary before the full charge can be put in, machine charging might be more advantageous.

Other considerations favouring machine charging in larger furnaces are :

(*a*) Better scrap distribution is possible in the furnace—heavy pieces of material can be placed under the electrodes where the heat is most intense.

(*b*) The addition of comparatively large quantities of alloying metals and slag-forming material can be carried out more expeditiously.

Refractories

The severity of the conditions to which refractory linings are subjected in the basic arc furnace is indicated by the fact that the life obtained is generally only one-third to one-half of that obtained under comparable conditions in the open-hearth furnace.

During recent years there has been considerable activity in Britain in the study of basic arc furnace linings, and a large amount of research work has been carried out and published. In 1940 the Basic Furnace Linings Committee was formed by a number of interested firms who agreed to pool their knowledge and to carry out joint research on dolomite linings for furnaces, and under this committee a Technical Panel was set up and deputed to develop the use of dolomite in monolithic linings of furnaces. This Committee[4] dealt with the application of monolithic dolomite to the electric arc furnace in addition to many other applications such as the basic open hearth, the Bessemer converter, etc.

In 1942, at a meeting of the Open Hearth Refractories Joint Panel of the Iron and Steel Industrial Research Council* and the British Refractories Research Association,† the Electric Furnace Linings Sub-Committee was appointed to consider problems relating to electric furnace refractories. As a preliminary, this Committee carried out a survey of typical British electric arc furnace refractories for furnaces ranging from 2 tons' to 30 tons' capacity. As a result of this survey it was evident that there was a real problem concerning the construction of basic electric furnace roofs, and it was decided to study the problem of roof construction in the first instance. The effects on the roof life of certain features of roof construction and furnace operation were deduced, and on the basis of the conclusions reached, a simplified design of roof was recommended, popularly known as the 'standard' roof. The details of the work of this Committee to date were published in the Third Report on Refractory Materials.[5]

Another very important contribution entitled, "Dolomite Linings for Basic Electric Arc Furnaces," was made by E. C. Brampton, H. Parnham, and J. White.[6] In this investigation a review was made of the refractory performance data supplied by the users of furnaces in which 100% dolomite brick linings were employed, and the general method of installing such linings was indicated and illustrated by diagrams. This investigation was primarily concerned with the

* Reported in a paper by Sunström, which includes a comprehensive bibliography of recent papers relating to electric arc furnace practice.

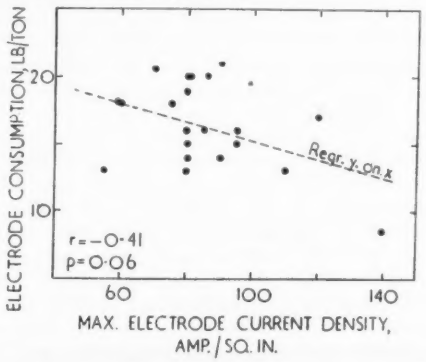


Fig. 5—Relationship between electrode consumption and current density

* Now the British Iron and Steel Research Association.

† Now the British Ceramic Research Association.

performance of semi-stabilized dolomite brick side-wall linings and the reason for their wear.

Further information on typical electric furnace lining practice is given in Table II of the present paper.

This paper is intended to indicate only the general trend of British practice, and for more detailed information the publications referred to[4, 5] should be consulted.

Hearths—Next to the casing there is usually about 2½ in. of refractory insulating material or bricks, and then about 3 in. of firebricks. Above this, there are usually magnesite or dolomite bricks, or both, to a thickness of 6 to 9 in., the shape being adjusted to the contour of the hearth. Above the basic bricks is rammed a lining of dolomite, varying in thickness from 2 to as much as 12 in. The practice before the war was to use coarse dolomite bonded with hot tar, but as a result of the work carried out by the Basic Furnace Linings Committee, much attention was focused on the use of tarred dolomite specially graded to provide maximum packing density. The result of this innovation was an improvement in the performance of dolomite hearths. The most recent trend in British practice is the use of specially graded graphitized dolomite. It is claimed that this material sinters to a highly impervious rock-like mass which is very resistant to mechanical abrasion and chemical attack. In fact, it has been the experience of manufacturers of large tonnages of low-carbon stainless varieties of alloy steels, who have in the past encountered great trouble with excessive wear, that continuous production of this type of steel is now possible on such a hearth. Doubtless, a large proportion of basic electric steelmakers will employ this type of hearth in the future.

Tapping Arches and Jambs—In the past, silica bricks were chiefly used in the construction of the tapping arches and jambs, but the modern tendency is to use basic bricks.

Door Arches—Silica is chiefly used for door arches, although again the tendency is towards an increasing use of basic brick.

Side-Walls—Side-walls have been made in a variety of ways, of which the following are examples :

(1) 14 to 18 in. of magnesite or chrome magnesite bricks to the level of one course above the sill plate, then a neutral join of crushed chrome ore, and above this silica bricks.
(2) 9 in. of chrome magnesite bricks on the working face, with a backing of 4½ in. of magnesite and 4½ in. of firebrick.
(3) 9 to 18 in. of dolomite brick, with a top course of chrome magnesite brick.
(4) Rammed tarred dolomite.
(5) Graphitized dolomite.

Because the cost of side-walls per ton of steel is a comparatively minor item and repairs can be so quickly carried out, factors other than cost usually determine their method of construction. It is, however, very important that a consistent guaranteed life should be obtained so that repairs may be carried out during non-melting weekend periods, thus avoiding production delays. Although silica bricks are still used by a small number of British electric steelmakers because they consider that the cost per ton of steel is lower than with basic refractories, typical modern British practice is to use basic linings. Silica linings wear rapidly near the slag line, causing excessive fluxing of the dolomite banks and increasing the slag burden. Also, the composition of the slag is more difficult to control owing to the indeterminate amount of silica dripping from the side-walls on to the banks and into the slag. In addition, the wear of silica bricks is so severe that the linings ultimately collapse during the week, thus causing undue serious delays in production which would have a more adverse effect on the cost. As a result of these failings of silica linings, basic materials have been widely adopted by British electric steelmakers. In present-day practice, linings are usually constructed with chrome magnesite bricks, or semi-stabilized dolomite bricks. Though superior to silica, these linings do wear by flaking or spalling, and intensive research work has been carried out in an attempt to overcome or minimize this trouble, but so far without success. As a result, the metal-cased basic lining has been re-introduced. The metal case oxidizes in service to iron oxide, which reacts with the basic material to form a cement between the join of the bricks, and results in a more or less monolithic face in service. In this way failure due to spalling or flaking has been greatly reduced and an increased life has been achieved. Another recent technique is to ram the linings with graphitized dolomite.

Roofs—The investigation carried out by the Electric Furnace Refractories Sub-Committee indicated that great variations in the performance of electric furnace roofs were being experienced by electric steelmakers. In the first place there was a notable difference between removable roofs and fixed roofs, the fixed roofs generally having a much better life. Again, although most steelmakers employed silica bricks for the construction of their roofs, there was a great variety in the shapes and sizes of bricks employed. A number of users employed specially designed 'tailor-made' roofs, whereas others employed much simpler shapes, and depended on cutting the bricks to make them fit.

The Committee also drew attention to the importance of the rise of the roof, expansion allowances, and the construction of the roof ring itself.

As a result of this work it may be safely concluded that the average life of roofs in British electric furnace practice has been materially improved, although a great deal of work still remains to be done.

Another major contribution of the Committee was to develop a simplified design of roof construction in which a limited number of brick shapes were devised by which the majority of furnace roofs in British practice could be constructed, thus simplifying the problem of the brickmaker by limiting the number of special shapes to be produced, and making the problem of storage in the steelworks much easier.

Silica roofs tend to flux rapidly when operating at the higher temperatures, silica dripping into the slag and affecting the composition and bulk of the slag. For special cases where higher temperatures than normal are required, experiments are now being carried out with basic roofs, and it is possible that the British electric furnace of the future will be all-

Table III

DETAILS OF ARC FURNACES AT THE OPENSHAW WORKS

Nominal Capacity, tons	No. in Shop	Transformer Rating, kVA.	Output, V.	Charging Mechanism	Electrodes
Small Shop					
3	2	1500	Delta 165, 145, 125 Star 95, 84, 72	Basket	8-in. graphite
2	1	800	Delta 160, 140 Star 95, 85	Hand	6-in. graphite
Large Shop					
30	3	6000	Delta 180, 160, 140 Star 106, 94, 81	Machine	16-in. graphite
10	2	3500	Delta 182, 160, 140 Star 108, 95, 82	Machine	20-in. amorphous
5	1	2300	Delta 180, 160, 140 Star 114, 95, 85	Hand	14-in. amorphous

basic. In some special cases sillimanite roofs have been tried, but these have been successful only in small furnaces. In a few cases 42% alumina firebricks have been reasonably successful. A common cause of failure is spalling of the first three courses from the skewback, and this can be overcome by the use of firebrick.

Process

A description of standard electric steelmaking is superfluous here and, broadly speaking, general practice in Great Britain follows the normal lines. In details, each works tends to follow methods which have been found to give the best results for any particular quality at that plant. Acid furnaces are generally limited to small units in foundries, the bulk of electric steel for ingots at present being made in basic furnaces.

The choice of current during melting to give the greatest power input at any given voltage has not been studied to any great extent in Great Britain. Since the power-input/current relationship, at any given voltage, has the form shown in Fig. 7,* the current should be chosen to run the furnace at the optimum value of power input in the arc. Though the current giving maximum power in the circuit can be determined fairly easily, the determination of optimum current for maximum arc power is more complicated. Up to the present the concentration of British electric steelmakers on high-priced 'quality' steels has minimized the need for special attention to choice of optimum currents for each voltage, but the possible extension of electric steelmaking to lower-priced steels is now causing more interest to be taken in this matter.

One feature of British practice which is now almost universal, is control of the bath temperature by the immersion pyrometer; this method is very easily applied in the electric process.

* Reproduced from "The Efficient Use of Fuel," by permission of H.M. Stationery Office.

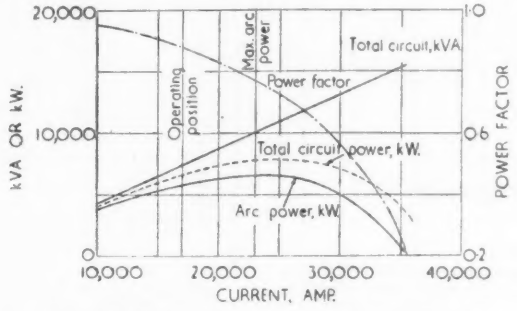


Fig. 7—Characteristic curve of arc furnaces

ELECTRIC STEELMAKING PLANT AND PRACTICE

The following description of plant and process at typical electric furnace plants in Great Britain will give an idea of British practice as a whole.

The Openshaw Works, Manchester

The electric steelmaking plant at the Openshaw Works of the English Steel Corporation, Ltd., at Manchester, is one of the more modern plants in Britain, having been laid down in 1940. In effect, it consists of two separate shops. The smaller contains three small arc furnaces and an induction furnace, and is used for the production of high-speed steel, tool steel, heat-resisting steel, and other special alloys. The large shop contains six arc furnaces ranging in capacity from 5 to 30 tons, and producing carbon and constructional alloy steels.

The main characteristics of these furnaces are listed in Table III.

The induction furnace operates at a frequency of 2000 cycles, with a maximum power output of 200 kVA. All the arc furnaces are of the Heroult pattern and are on floor level, with transformers below ground. Roofs and arches are of silica brick, and the side-walls are of chrome magnesite. The side-walls of the 30-ton furnaces are 18 in. thick, and those of the 12- and 5-ton furnaces are 14 in. thick. The original bottoms were constructed with magnesite brick next the casing, then stabilized dolomite above, and dolomite linings; the present practice is to use

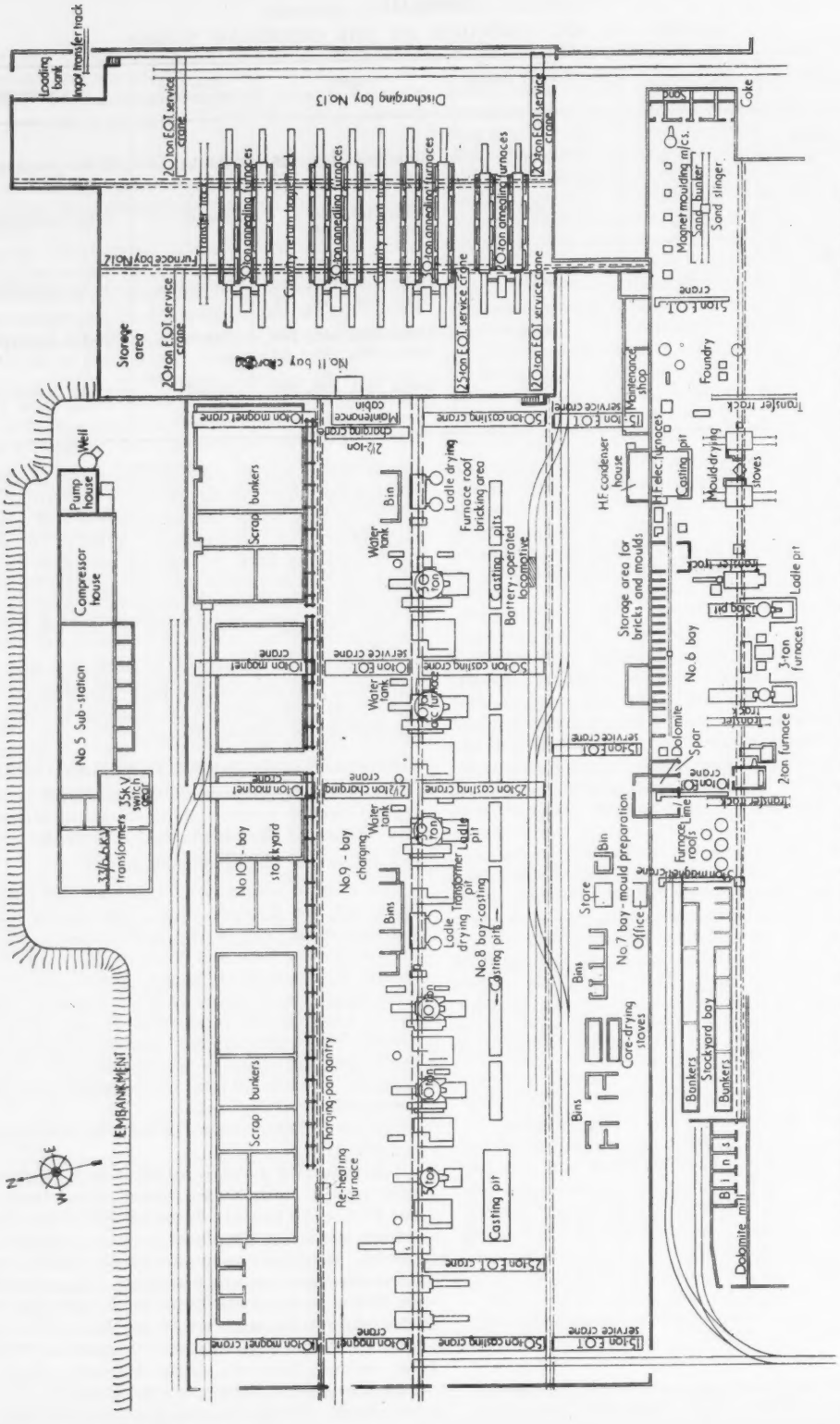


Fig. 8—General layout of the electric melting and annealing department at the Openshaw Works, Manchester

graphitized dolomite monoliths, which are found to give very satisfactory service.

The general layout of the plant is shown in Fig. 8, and a photograph taken on the melting stage is shown in Fig. 9.

Stockyard (*No.* 10 *Bay*)—In the spacious stockyard (600 ft. long × 80 ft. wide) the different types of scrap are stored in a series of bunkers. The pans are loaded by 48-in. dia. magnets, and are then taken away to the charging bay on the gantry.

Charging Bay (*No.* 9)—Here again the provision of adequate working space has been a major consideration. This bay is 800 ft. long × 60 ft. wide, and is served by two 10-ton E.O.T. cranes and two 2½-ton overhead charging machines.

Casting Bay (*No.* 8)—Eight casting pits, all 6 ft. deep and of various lengths from 35 to 60 ft., are provided. In addition, there are facilities for stripping the ingots before they are taken by electric truck to the annealing furnaces in bays 11 to 13, and for drying the ladles by means of a special swing drying equipment using town's gas. Three 50-ton and two 25-ton E.O.T. casting cranes are adequate for this bay.

Annealing Plant (*Bays* 11 *to* 13)—Details of the annealing plant are not within the scope of this paper, but a brief mention is included for the sake of completeness. The plant consists of three bays: the charging bay, the furnace bay, and the discharge bay. The eight annealing furnaces, fired by town's gas, are each divided into four chambers. In the case of the six larger furnaces, each chamber holds 30 tons, while the chambers in the smaller furnaces have a capacity of 20 tons. The charging bay is served by one 30-ton and two 20-ton E.O.T. cranes, and the discharge bay has two 20-ton E.O.T. cranes.

The following data show the working of a typical charge of carbon–chromium steel:

Cast No. HG8652—Carbon–Chromium Steel, Made on 31st December, 1948

The charge consisted of the following:

Carbon–chromium scrap	18,500 lb.
Hykro scrap	4500 lb.
Carbon scrap	31,500 lb.
Carbon–chromium turnings	16,500 lb.
Total	71,000 lb.

In addition to the above, 2000 lb. of limestone and 500 lb. of broken electrode were also charged.

10.10 Power on, 179 V.
15.10 Power on, 104 V.
15.20 Clear melt
15.20 Rabbled, and sample taken (1·00 C, 0·28 Ni, 0·16 Mn, 0·031 P). Slag sample *A* taken.
15.25 First pull-off of slag, clear bath, 1000 lb. of limestone charged
15.50 200 lb. of iron ore charged
16.05 Rabbled, and sample taken (0·90 C, 0·020 P)
16.25 Second and final pull-off of slag. 1000 lb. of limestone charged, 240 lb. of ferro-silicon and 100 lb. of fluorspar added to form white slag. Slag sample *B* taken
16.50 White slag obtained
16.55 Sample taken after good rabble (0·87 C, 0·17 Mn, 0·82 Cr). Slag sample *C* taken
17.05 Sample taken after good rabble (0·86 C, 0·84 Cr, 0·030 S)
17.45 Sample taken after good rabble (0·023 S). Temperature 1585° C.

Fig. 9—View of the electric furnace plant at the Openshaw Works, Manchester

17.50 1265 lb. of pig iron and 50 lb. of ferro-silicon charged
18.10 650 lb. of ferro-chromium and 70 lb. of ferro-manganese charged
18.30 60 lb. of ferro-manganese and 60 lb. of ferro-silicon charged. Slag sample *D* taken
18.50 Tapped. Temperature 1575° C.
18.55 Commenced casting 19 × 15½ in. square ingots (31½ cwt.). All ingots cast through 1¼-in. nozzle
19.23 Normal casting conditions with medium 'cream' on ingots
19.23 Finished casting

Slag Analysis, %

	Sample *A*	Sample *B*	Sample *C*	Sample *D*
SiO_2	28·60	24·30	19·70	23·60
Fe_2O_3	1·60	1·50	0·50	0·10
FeO	5·20	4·50	0·80	0·40
Al_2O_3	2·80	2·50	2·40	2·80
MnO	10·50	6·30	0·56	0·20
CaO	46·60	53·20	69·00	66·70
MgO	3·00	5·40	2·05	2·90
Cr_2O_3	1·40	1·10	0·10	0·37

Steel Analysis, %

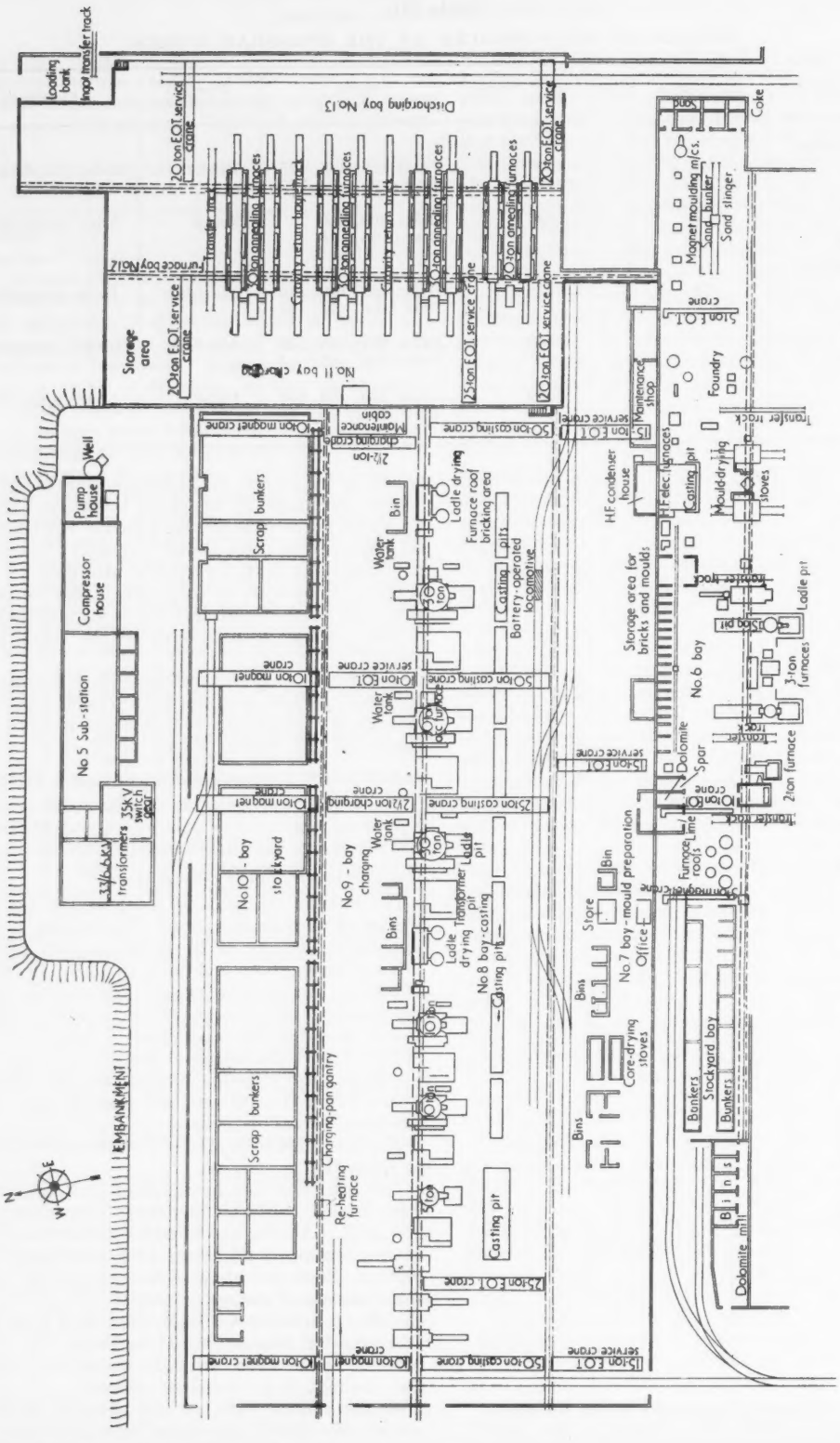
	Actual	Specification
C	0·99	0·95–1·10
Si	0·20	0·20–0·30
Mn	0·35	0·25–0·40
S	0·012	0·025 max.
P	0·018	0·025 max.
Ni	0·21	0·30 max.
Cr	1·46	1·30–1·60
Mo	0·05	Low

High-Frequency Induction Furnace Plants

So far this paper has dealt mainly with arc furnace practice, but the development of the high-frequency induction furnace has taken place to a remarkable degree in Great Britain. The first British commercial high-frequency furnace (5 cwt. capacity) was installed at the works of Messrs. Edgar Allen and Co., Ltd., in 1927, to replace the old crucible furnaces for making tool and magnet steels. The first large furnace* (5 tons' capacity) was installed by the Electric Furnace Co., Ltd., in Sweden in 1933, and this was quickly followed by a similar installation in Britain, though today most high-frequency furnaces are less than 1 ton in capacity.

The special advantages of the high-frequency

* Smaller furnaces operating on a spark gap, as distinct from a motor generator, were in existence at an earlier date.



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MnO	10·50	6·30	0·56	0·20
CaO	46·60	53·20	69·00	66·70
MgO	3·00	5·10	2·05	2·90
Cr_2O_3	1·40	1·10	0·10	0·37

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The special advantages of the high-frequency

* Smaller furnaces operating on a spark gap, as distinct from a motor generator, were in existence at an earlier date.

furnace centre upon the absence of electrodes, though the self-stirring action in the metal can also be regarded as advantageous in some respects. The advantages can be summarized thus :

(*a*) The manufacture of high-quality tool and magnet steels is easier and cheaper, and is subject to closer control, than in crucible furnaces.

(*b*) Induction furnaces are specially convenient for making the small casts of high-alloy steel required for foundry work.

(*c*) Larger units can produce low-carbon stainless steel and high-alloy steels without carbon pick-up.

(*d*) Melting under reduced atmospheric pressure is possible if desired.

The chief drawback is often stated to be the high capital cost per unit of capacity, but this can be (at least in part) offset by the high rate of production. The ideal electric steel plant contains both arc and induction furnaces, as a constant source of low-sulphur and low-phosphorus scrap of known composition is then available in the mill scrap from the arc furnaces for use in the induction furnaces.

High-Frequency Plant at Firth-Brown Steels, Ltd.

The high-frequency plant at Firth-Brown Steels, Ltd., was laid down for the production of (i) a wide variety of stainless steels, particularly those of the lowest carbon content ; (ii) heat-resisting types, including the modern complex alloys ; and (iii) tool steels. The furnaces are also used for making high-quality constructional steels, in ingot sizes within their capacity.

General Layout—This is shown in Fig. 10. The installation, consisting of two 5-ton, one 25-cwt., and two 10-cwt. furnaces, is accommodated in bays which at one time held Siemens open-hearth and latterly old-type electric arc furnaces. This fact explains the unusual position of the motor-generator system, the number of bays, cranes, etc., and the isolated position of the 25-cwt. furnace. Whilst the arrangement may not conform with modern conceptions of high-frequency melting-shop layout, because of the adequate number of cranes available and the non-interference of sections with each other, the plant is actually found to operate very satisfactorily.

The plant—comprising scrap bay, combined working bay and scrap bay, and casting bay—is served by a branch railway line and a roadway running at right-angles to the bays. Details of the furnaces are given in Table IV. The scrap bays which once served the old electric arc furnaces are quite adequate for the present furnace requirements. In view of the various qualities produced and the necessity of using the maximum percentages of returned scrap, segregation of scrap is essential. A system of scrap control with special marks for identification and segregation is well maintained throughout the various sections of the works, and, in general, the rejection of casts due to the use of improper scrap is negligible.

Working Bay—The working platform for the 5-ton and 10-cwt. furnaces is at floor level. The 5-ton furnaces situated between the working and casting bays are served by electrically operated jib cranes, so that charging operations can proceed without hindrance. The smaller 10-cwt. furnaces, being hand-charged, do not require crane services during melting operations.

The isolated 25-cwt. furnace, with its 6-ft. high working platform, is in a temporary position, and to render it independent of the main bay cranes, materials from the scrap bay are delivered by a mono-rail hoist which, if necessary, can also be used for charging. In addition, there is an overhead crane for pit work, tapping, and casting.

Main Casting Bay—Ample crane capacity is provided in the main casting bay ; the 5-ton furnace ladle pits are sufficiently large to accommodate ladles up to 20 tons' capacity. The great advantage of this separate casting bay is that the preparation of moulds and ladles, and casting, etc., do not interfere with the charging and preparation of the charge.

Ingots, after stripping, are generally examined when cold, and then delivered by rail or lorry to a separate section for chipping, grinding, or machining, but if necessary, ingots can, without difficulty, be delivered hot direct from the pit by rail or road in covered vehicles.

Tool steels of the high-speed 18/4/1 group, or of the plain carbon type, are generally required in small ingots, and the two 10-cwt. furnaces can normally supply the quantity of steel required in these moulds. The larger furnaces are used for the manufacture of steel in a range of ingots from 5 cwt. to 10 tons. Larger stainless ingots up to 45 tons, and stainless steel of normal carbon contents, have been and are produced in an adjoining battery of arc furnaces of 10 to 30 tons' capacity.

Basic Linings—The early troubles encountered with the installation and maintenance of the monolithic dolomite lining have been largely overcome, and with the advantage of the double box units, no serious

Table IV

ELECTRICAL EQUIPMENT OF HIGH-FREQUENCY FURNACES AT FIRTH-BROWN STEELS, LTD.

Furnace Capacity	Generator				Motor				Condenser kVA.
	Voltage	Amp.	kW.	Frequency, cycles	Voltage	B.H.P.	R.P.M.	Type	
10 cwt.	1500	133	200	2220	440	300	2950	Squirrel-cage	2700
10 cwt.	1500	133	200	2220	440	300	2950	Squirrel-cage	2565
25 cwt.	2000	325	650	500	6600	1400	1500	Slip-ring	5137·5
5 tons	1500	733	1100	1500	6600	1675	1500	Synchronous	20,280
5 tons	3000	500	1500	1000	6600	2250	1500	Synchronous	23,545

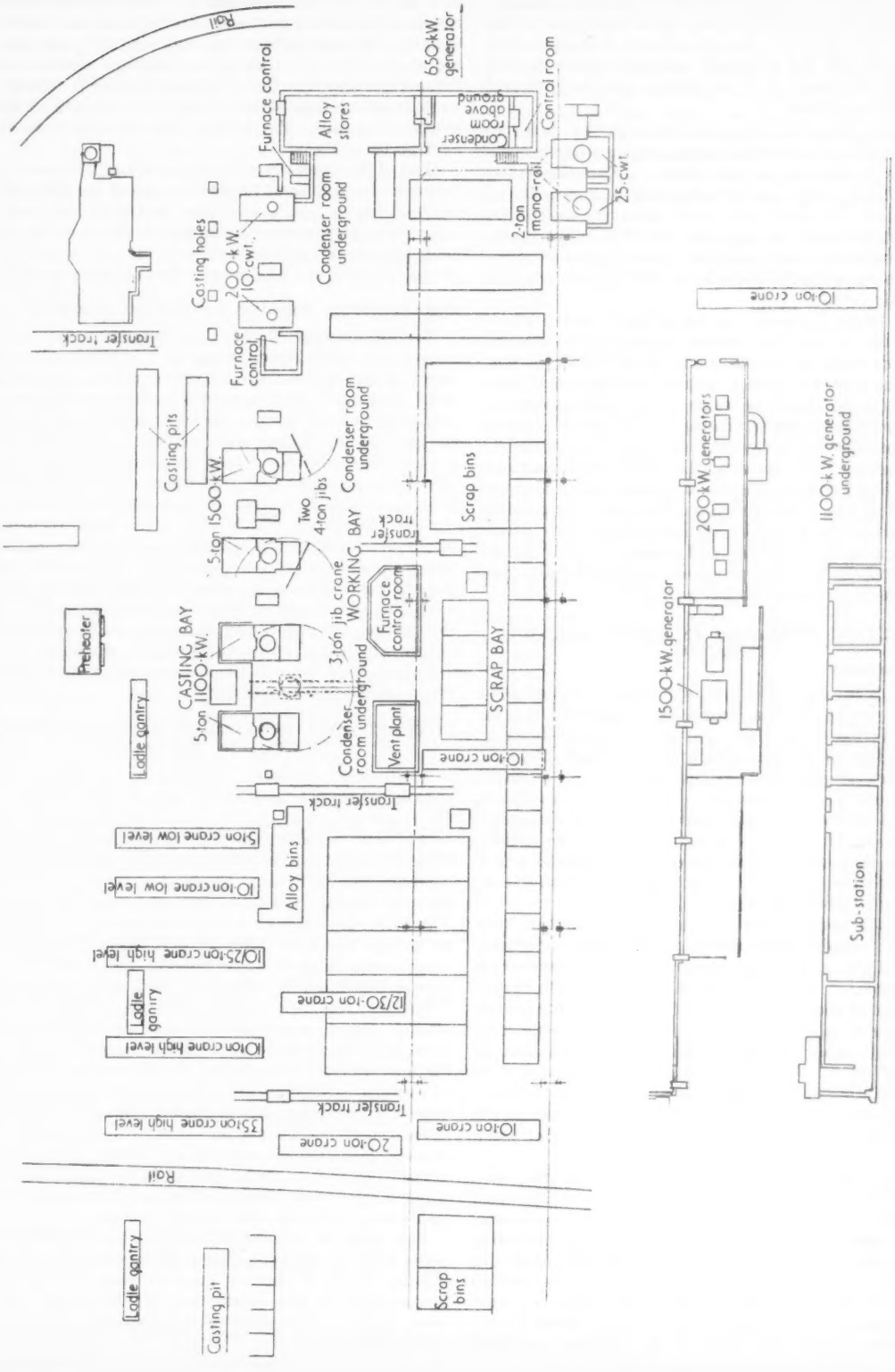

Fig. 10—General layout of the high-frequency induction furnace plant at Messrs. Firth-Brown Steels, Ltd., Sheffield

loss of output is experienced by a mid-week change-over from a worn-out lining to a spare lining previously dried and preheated. The advantages of this practice, compared with the system of alternate melts in each box, are debatable, and the choice must be governed by local conditions.

General Remarks—The acid-lined 10-cwt. furnaces were originally installed to replace the crucible process for the production of tool steels. Experience has shown that, with careful selection of materials (a proportion of which may have been pre-melted by the basic process), the superior control of temperature, slag conditions, and analysis, gives a product more reliable than that obtained by the original crucible method.

The larger furnaces are basic-lined, and produce the bulk of the low-carbon stainless steel, some qualities requiring a carbon content of 0·05% or less.

In the past, the general opinion has been that very little refining could be done in the high-frequency furnace owing to the small area of slag–metal interface and the difficulty of keeping the slag at a sufficiently high temperature. However, by taking full advantage of the basic system, in spite of the absence of a superheated slag as exists in the arc furnace, it is possible to promote the formation of lime silicate slags, which will, during the oxidizing and refining stage, function as effectively as other processes, to give sulphur and phosphorus contents as low as 0·01%.

ELECTRIC FURNACES IN STEEL FOUNDRY PRACTICE

Arc Furnaces

The application of electric arc furnaces in foundries began almost as soon as did ingot production from these furnaces, so that arc furnaces have been in use in British steel foundries for more than 30 years. Foundry requirements limit the size of furnace which can be used because of the restricted amount of steel which can be absorbed in the form of castings at any one time. Thus, foundry furnaces are usually within the capacity of 3 to 5 tons, although a few furnaces are in use with capacities of less than 3 tons, and up to about 10 tons.

Electric arc furnaces have a distinct advantage over the commonly used side-blown converter, in that alloy steels may be more readily made in an electric arc furnace. On the other hand, there is a disadvantage in that the time cycle is longer than with the side-blown converter, so on that account the converter is more flexible, particularly in relation to carbon steels. The recent war gave an impetus to the use of electric arc furnaces in the foundry because of the demand for alloy steels and because of its relatively simple design as a plant unit and the small space required for its installation.

In a number of foundries engaged on the mass production of castings, the flexibility was improved and the supply of electric steel was made continuous by a special arrangement of the plant by providing a low-powered furnace to hold liquid steel ready for use, the steel being made in a smaller high-powered furnace built adjacent to it. The furnaces were arranged so that the smaller one, usually about 4 tons' capacity, could pour steel in the finished condition into the larger one from which it was withdrawn as required for casting purposes. This system has worked equally well with carbon steel and with 12% manganese steel. The principle of a ' holding ' electric arc furnace has also been found to be applicable to foundry work in which side-blown converters are used as the steelmaking unit. The holding furnace may have an acid or basic lining.

Most of the electric arc furnaces used in British steel foundries employ basic linings because of the difficulty of obtaining suitable low-sulphur and low-phosphorus scrap for acid practice. Nevertheless the value of the acid process is appreciated, *e.g.*, it is capable of producing steel at a higher rate than the basic process.

High-Frequency Induction Furnaces in Foundries

The advantages of the high-frequency induction furnace for steel manufacture in the production of steel castings were recognized very early in its development, and many British steel foundries are equipped with this type of plant. Its chief advantage lies in the production of very highly alloyed steels because the process allows for a very high degree of recovery of alloying elements from the scrap used, with freedom from contamination from outside influences, such as carbon absorption, which very often limits the use of the arc furnace. In addition, as the units can be run economically in comparatively small sizes, the majority of such furnaces have a capacity below 2 tons in weight. Intricate castings are easier to produce by this process because of the wide range of temperature within which steel can be accurately controlled.

Linings may be acid or basic, depending on the steel made and on local conditions.

FUTURE DEVELOPMENTS IN ELECTRIC STEELMAKING IN BRITAIN

The future of electric steelmaking in Britain will obviously depend to a great extent upon trends in the relative cost of electric power as compared with other fuels. Pending the widespread development of atomic energy, which even the most optimistic forecasters agree will take a considerable time, coal is likely to remain the main national source of power. Therefore the relative cost of electricity is unlikely to change much, so that at first sight there would seem to be limited scope for any great increase in electric steelmaking compared with other processes.

Nevertheless, the unique advantage held by the electric process in the production of low-sulphur steels is of great importance at a time when fuels available for open-hearth steelmaking are showing a tendency to increase in sulphur content and when steel specifications are becoming more stringent. Already a number of British firms have made a series of trial casts on less-specialized steels, sometimes working a single-slag process similar to that worked in the open hearth. Under these conditions the costs have been lower, even competing with the open-hearth process.

One plant is successfully making low-sulphur rimming steel for deep-drawing purposes, and during the closing stages of the war another plant turned over temporarily to the production of ' balanced ' mild-steel ingots. An outline of these special processes is given below.

Manufacture of Rimming Steel

The manufacture of rimming steel for deep drawing, in the basic electric arc furnace, is carried out by Messrs. Wm. Beardmore and Co., Ltd., both at the Parkhead Works, Glasgow, and at the Linwood Works, Paisley. The steel is supplied in 7-ton rectangular ingots, for rolling at the customers' works, to the following specification: Carbon 0·06%, manganese 0·30–0·35%, and sulphur 0·03% max.: other residuals are to be as low as possible.

Since the ingots are rolled elsewhere, no mill scrap is available, so reliance has to be placed on purchased scrap and turnings. The normal mixture is as follows: Purchased scrap 17 tons, mild-steel turnings 3 tons, and burnt lime 1120 lb.

It is usual practice to charge the heavy or good-packing scrap next to the bottom, finishing off with mild-steel turnings. The lime is charged in two lots, a 5-cwt. pan after the first 5 tons of scrap, and the remaining 5 cwt. after 15 tons of scrap. If the scrap is of such quality as to necessitate partly melting before the last of the scrap can be charged, then the second 5 cwt. of burnt lime is charged in the part-melted bath before the remainder of the scrap is charged. The furnace is machine-charged through the front door.

The aim is to melt out with a (S)/[S] ratio of 10 : 1, so that at the clear-melt stage slag and metal samples are drawn for carbon, sulphur, manganese, and total iron. The usual practice at this stage is to commence hand-feeding burnt lime whilst awaiting the laboratory result. Depending on conditions prevailing, anything up to 10 cwt. of burnt lime may be fed until the sulphur has dropped below the specified 0·030% max. A carbon melt of 0·20% is aimed at, and scale is fed to reduce this carbon to 0·060% max. and, at the same time, to raise the total iron in the slag. If the carbon melt should be greater than 0·20%, ore is fed to bring the bath on to the boil and thereafter fed down with scale. The finishing addition of ferro-manganese was formerly added to the bath before tapping, but by decreasing the size of the tap-hole and by pouring from below the slag, it is now found possible to add the ferro-manganese to the ladle and so reduce the loss of manganese.

Particulars of six recent charges are given in Table V. The following is a typical sequence of operations:

Time	Operation
12.30	Commenced charging
	25 pans of scrap and part of lime
13.30	Power on
15.30	Power off
	Remainder of lime and 9 pans of scrap
15.55	Finished charging
	Power on
17.15	Melted
18.35	Tapped

Average electrical consumption = 11,500 kWh./charge = 660 kWh./ton

Average electrode consumption = 16 lb./ton.

Production of 'Balanced' Mild Steel

The production of 28–32-ton tensile 'balanced' mild steel in a 20-ton electric arc furnace was worked for a time at the Distington Works of the Ministry of Supply, at Cumberland, and managed by The United Steel Companies, Ltd. Owing to completion or cancellation of alloy-steel contracts in September, 1944, it was decided to complete the year on 28–32-ton tensile, balanced mild-steel ingots to the following analysis.

C, %	Mn, %	S, %	P, %
0·15–0·20	0·40–0·60	0·05 max.	0·05 max.

The scrap available was rail scrap, acid 0·05 S and P (light stampings), Bessemer mill discard, the works' mill discard from previous plain carbon production,

Table V

DETAILS OF RIMMING-STEEL CHARGES

	Time	Steel Analysis, %					Slag Analyses, %		Ratio (S)/[S]	Additions, lb.		
		C	Mn	S	P	Ni	Fe	S		Lime	Scale	Fe.Mn
No. 1. Melted	12.45	0·10	0·24	0·028			21·17	0·39	14·0	336	...	...
	13.30	0·07	0·19	0·026			21·28	0·37	14·3	...	...	336
Tapped	13.55	0·05	0·31	0·018	0·005	0·16				...	...	...
No. 2. Melted	05.00	0·10	0·26	0·033			15·45	0·44	13·3	336	224	...
	05.55	0·06	0·11	0·026			18·59	0·51	16·1	336	...	364
Tapped	06.20	0·06	0·34	0·022	0·007	0·19						
No. 3. Melted	22.15	0·13	0·30	0·035			13·89	0·34	9·7	336	224	...
	23.00	0·06	0·24	0·028			18·70	0·40	14·3	336	...	280
Tapped	23.35	0·07	0·32	0·023	0·011	0·09						
No. 4. Melted	05.30	0·15	0·31	0·039			10·64	0·44	11·3	672	280	...
	06.10	0·07	0·21	0·028			18·59	0·42	15·0	448	...	308
Tapped	06.35	0·07	0·35	0·027	0·018	0·09						
No. 5. Melted	15.45	0·14	0·31	0·033			14·78	0·50	15·0	672	392	...
	16.35	0·07	0·20	0·020			22·68	0·51	25·5	112	...	336
Tapped	17.05	0·065	0·34	0·021	0·005	0·13						
No. 6. Melted	17.10	0·14	0·26	0·032			19·60	0·53	16·5	336	392	...
	18.05	0·06	0·18	0·023			23·85	0·55	24·0	336	...	364
Tapped	18.35	0·06	0·32	0·022	0·008	0·13						

and the works' pit scrap. No plain carbon turnings were available.

The basket charge was made up aiming to melt out at 0·20–0·30% of carbon, and where possible consisted of heavy and light scrap in such proportions as to give a rapid melt. A weight of 9 cwt. of limestone was put in with the charge, with further additions during the melt.

When clear melted, the bath was put to boil with ore, and one sample was taken for carbon, manganese, sulphur, and phosphorus. Further loss of carbon was judged on fracture test, and when within the required limits, ferro-manganese, ferro-silicon, and lime were added to steady the bath. The amount of ferro-silicon added to the ladle on tapping depended on the state of the tapping sample, aiming at a 0·06% silicon finish.

Open-top and open-bottom narrow-end-up moulds were used, with direct pouring, the maximum ingot weight of 47 cwt. being specified by the rolling mill.

The ingots were balanced by the addition of aluminium chips to the moulds, the number of chips used depending on the condition of the metal.

The following data are typical of the general practice during the three months, aiming at a 4-hr. cycle ('power-on' to 'power-off'), and giving six casts per 24 hr. The best actual performance was 28 casts in a week, starting on a Monday at 6.0 A.M. No serious attempt was made to remove sulphur.

Details of Casts Nos. E1765 and E1766

The specifications of the two casts were as follows :

Cast No. *E*1765	Cast No. *E*1766
0·15–0·20% C	0·15–0·20% C
0·40–0·60% Mn	0·40–0·60% Mn

Details of Charge :

	Cast No. *E*1765 lb.	Cast No. *E*1766 lb.
0·05 S and P acid scrap	21,280	18,368
Rails	18,704	24,304
Pit scrap	2240	1792
Mn–Mo scrap	4480	4928
Mill scrap	3360	...
Limestone	1008	1008
Ore	336	840
Ferro-manganese (ord.)	302	292
Ferro-silicon	154	140
Aluminium	3	3
Ingot weight	47,376	47,376
Scrap weight	560	224
Melting loss	2923	3067
	%	%
Ingot yield	93·17	93·54
Metallic yield	94·27	93·98

Time of Working :

	Cast No. *E*1765	Cast No. *E*1766
Tapped last charge	07·50	12·10
Commenced charging	08·22	12·44
Power on	08·43	13·02
Melted	11·15	15·15
	(Units used : 11,300)	(Units used : 10,200)
Tapped	12·10	16·37
	(Units used : 13,200)	(Units used : 12,900)
Finished teeming	12·40	17·05

Additions and Samples :

Cast No. *E*1765	Cast No. *E*1766
During melt : 224 lb. limestone	During melt : 56 lb. limestone
11.15 (melt) 280 lb. ore, 224 lb. limestone	15.15 (melt) 560 lb. ore, 112 lb. limestone
11.24 Sample : 0·23–0·24 C, 0·33 Mn, 0·043 S, 0·033 P	15.36 Sample : 0·026 C, 0·028 Mn, 0·042 S, 0·035 P
11.43 224 lb. limestone, 10 lb. spar, 112 lb. Fe.Mn	16.10 280 lb. ore, 224 lb. limestone
11.52 336 lb. limestone, 40 lb. spar, 94 lb. Fe.Si	16.20 224 lb. limestone, 60 lb. spar, 112 lb. Fe.Mn
12.03 168 lb. limestone, 10 lb. spar, 190 lb. Fe.Mn	16.26 336 lb. limestone, 40 lb. spar, 80 lb. Fe.Si
12.10 (tap) 60 lb. Fe.Si to ladle	16.32 172 lb. limestone, 60 lb. spar, 180 lb. Fe.Mn
Sample : 0·20 C, 0·56 Mn, 0·07 Si, 0·041 S, 0·022 P	16.37 (tap) 60 lb. Fe.Si to ladle
	Sample : 0·17 C, 0·58 Mn, 0·06 Si, 0·039 S, 0·029 P

Details of Teeming :

	Cast No. *E*1765		Cast No. *E*1766	
Nozzle size	1 in.		1 in.	
Time in ladle	3 min.		3 min.	
Pit setting	9×47-cwt., direct			
Teeming speed :	Sec.	No. of Chips of Al	Sec.	No. of Chips of Al
1st ingot	125	6	125	6
2nd ingot	123	6	116	4
3rd ingot	112	3	112	2
4th ingot	101	4	108	3
5th ingot	95	4	105	3
6th ingot	94	4	100	4
7th ingot	92	4	94	4
8th ingot	90	4	90	4
9th ingot	98	5	101	5

In the following rough analysis of the materials and costs over a four-week period, it should be noted that, owing to the necessity for employing surplus labour during the change-over period, the costs are higher than would normally obtain, and they have, of course, changed since this plant was operated :

Output	2208·8 tons
Output per hour (based on power-on to power-off only)	5·38 tons
Ingot yield	91·6%
Metallic yield	94·5%
Power consumption :	
Units per ingot ton	702
Units per ton of metallic yield	639
Electrode consumption	13½ lb./ingot ton

Materials used :	Lb./ingot ton
Pig iron	12
Scrap	2382
Ferro-silicon (75%–80%)	6½
Ferro-manganese	18
Aluminium	Trace
Foreign ore	37
Anthracite	1
Broken electrodes	3½
	2460
Less scrap recovered	70
	2390

Costs :	Shillings/ingot ton
Net cost of materials listed above	142·7
Fettling and fluxes	1·0
Pit refractories	0·4
Ingot moulds	6·1
Power (0·65 pence per unit)	38·0
Electrodes	12·4
Tonnage expenses (*e.g.*, wages paid on tonnage)	5·8
Time expenses (*e.g.*, wages paid on time)	33·7
Total	240·1

(Due allowance has been made in compiling the above costs for part of the melting shop being idle.)

The Use of Oxygen in Electric Furnaces

The experimental work and practice on the use of oxygen in electric furnaces, which has recently been carried out in the U.S.A., has been followed with interest in Great Britain, and a number of experiments, both along similar and on original lines, have been made. These experiments are as yet in too early a stage to provide any useful addition to the published literature, but the following outline is an example of what is being done at one works. At present, high-purity oxygen is being used, but if a source of medium-purity (tonnage) oxygen were available, this cheaper gas could be used without modification of the procedure.

The gas is supplied either from cylinders or, preferably, from a pipe line fed from the evaporators of a liquid-oxygen plant. In either case a pressure reduction valve is connected between the supply and the point of use. The only other equipment required is a length of rubber tubing and a supply of 'lances.' These lances usually consist of steel tubing, of $\frac{1}{2}$-in. bore and about 20 ft. long. A full-bore on/off valve is connected at one end for the convenience of the operator.

To feed oxygen, the lance is lifted on to the door sill, the door is opened slightly, and after turning the valve to the 'on' position, the melter pushes the end of the tube underneath the slag. He then feeds it forward slowly to keep it in that position until the lance is consumed.

The two main uses of oxygen are :

(1) To cut down solid scrap which remains on the banks, particularly near the doors, after the rest of the charge is molten. (For cutting-down scrap, the lance is applied directly to the pieces adhering to the banks.)

(2) To remove carbon. This application can be subdivided into :

(*a*) Carbon and constructional alloy steels.

(*b*) High-chromium stainless steels, in which carbon removal by ore is difficult.

The normal method of removing scrap from the sills and banks is to melt it off, resulting in high consumption of power and refractories. Oxygen provides an easy and rapid method of affecting dislodgement. When cutting-down in a 10-ton furnace, which is a common size in Britain, 3000 cu. ft. or more, of oxygen may be used. At a cost of about 12*s.* 6*d.* per 1000 cu. ft., this would raise the conversion cost by almost 4*s.* per ton. If medium-purity (tonnage) oxygen were available at 1*s.* 6*d.* per 1000 cu. ft., the cost would be much less, but control for this purpose would always be necessary because of the danger of wastage.

Oxygen considerably hastens rate of carbon removal from carbon and structural alloy steels. The rate of carbon drop can be twelve times (but it is more usually about seven times) as fast as that obtained by ore alone. The carbon drops rapidly and steadily, and this reduction continues for some time after the supply of oxygen is removed.

To decide whether oxygen can be used for carbon removal, each furnace and each charge must be considered separately. Where, due to too low an input during melting or because of the type of scrap, a charge appears to melt out but actually has unmelted metal on the bottom, the ore 'boil' must be used to clear the bottom and in such a case oxygen will not help. By the time the bottom is clear, the carbon is usually reduced to the figure at which the operator can proceed with refining. In such a case, oxygen will not clear the bottom. Where a charge is fully melted when flat, oxygen can be used immediately and time can be saved.

A few minutes are usually sufficient to achieve the necessary carbon drop, so that when the carbon has to be controlled to close limits, the operator must know the carbon content of the bath before going ahead, and to utilize the full value of the quick drop, the analysis for carbon must be carried out without loss of time.

The carbon in high-chromium stainless steels can be removed efficiently without undue loss of chromium. In this case, the temperature of the bath is increased before the oxygen is applied, and it is advisable also to use a higher gas pressure, otherwise an excessive amount of chromium is oxidized. If that happens, the slag thickens and it becomes almost impossible to work the furnace. In addition, the oxidation of chromium by gaseous oxygen releases large quantities of heat, which can seriously affect the refractories and furnace bottom. Under favourable conditions a reduction in carbon to 0·08% can readily be obtained. To counteract the increase in temperature, back charging of cold scrap can be used to cool the bath before tapping.

The foregoing paragraphs, based on practical experience, give a fairly representative picture of the present position of the use of oxygen in electric arc furnaces in Britain. There are, however, other aspects of the use of oxygen which must be considered before it can be accepted as a new tool in the manufacture of steel, and a considerable amount of further practical work will be necessary before it will be unreservedly accepted by the manufacturers of electrically melted steel. At the moment, it offers certain useful and intriguing advantages, but whether these can be used to increase production and to reduce costs of quality steels is still an open question.

Other Future Developments

Economies in electric steelmaking costs may perhaps be obtained by increasing the size of furnace, and by using electric furnaces to complete the refining of metal that has been melted by a cheaper method. Opinions vary on the optimum size of furnace ; in America, furnaces of a nominal 60-ton capacity are successfully used. Larger units exist, but are not regarded with universal favour.

Since so much of the power needed in electric furnace practice is consumed during the melting period, some attention has been given to duplexing, as practised elsewhere in Europe, so that electric steel quality may be obtained whilst a cheaper melting procedure is used. Apart from occasional trials, when the layout of the plant has permitted, duplexing has not been used in Britain as it has generally been felt that transfer costs, loss in yield, and other factors counterbalance the possible economies. British electric

steelmakers are, however, aware of the possibilities of such combinations as converter/electric and cupola/electric, and the British Iron and Steel Research Association is studying the technical and economic aspects. Certainly, such processes must be included in any considerations of the future development of electric steelmaking.

There is little doubt that future years will see an extension of electric steelmaking in Great Britain, but since a considerable increase in open-hearth and converter capacity is also envisaged, it is doubtful whether the proportion of steel will change appreciably. In spite of the growing interest in the use of the electric furnace for the manufacture of steels of intermediate cost, the main use of the process will undoubtedly continue to be the manufacture of the special qualities which maintain the world-wide reputation of the original manufacturers in this field.

Acknowledgment

The Electric Process Sub-Committee wishes to thank the managements of the numerous works concerned who have readily furnished data of plant and practice as material to be used in the preparation of this paper.

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B.I.S.R.A. Instruments

The British Iron and Steel Research Association is showing five instruments at the Physical Society's Exhibition at Imperial College, Kensington, from April 5th to 8th.

Sensible-Heat Meter

Measurement of thermal efficiency in furnaces operated at very high temperatures is of great importance to the steel industry. Frequently gas or oil temperatures are too high to be measured directly, and a sensible-heat meter is shown for measuring the heat content per unit volume in such circumstances. By this means a heat balance can be calculated.

A sample of the gases is continuously withdrawn through a water-cooled calorimeter, protected and supported by a water-cooled arm. The temperature of the cooled gas, which remains above the dew point, is accurately measured as it leaves the calorimeter by a fine wire thermocouple, and the rate of withdrawal is determined by metering the cooled gases. The gases are further cooled to room temperature and analysed, any condensed fluids being measured. In addition to its sensible heat per unit volume the temperature of the furnace gas as it enters the calorimeter may be deduced.

Dust Meter

B.I.S.R.A. is actively concerned in the investigation of silicosis in steel foundries, and a dust meter is shown which makes use of the Tyndall beam effect for comparative estimation of the dust concentration in air or gas atmospheres. A 30-watt filament lamp and lens system forms an intense and sharply defined divergent light beam which is passed axially through a cylindrical glass-walled sampling chamber. A sample of the atmosphere being analysed is continuously drawn through the sampling chamber by a motor-driven suction fan. The light scattered in a direction approximately normal to the illuminating beam is measured by four photo-multiplier cells which are positioned around the outside of the glass-walled sampling chamber.

Plate Thickness Meter

This instrument is designed for measurement of the thickness of a steel plate where only one side is accessible, and where there may be surface roughness, corrosion, and mill scale.

A saturation magnetic flux is set up through the thickness of the plate immediately below the pot-shaped electromagnet with search coil, which form the measuring head. The magnitude of the saturation flux so produced is a direct measure of the plate thickness and can be determined using a ballistic galvanometer excited from the search coil.

Four-Channel Electrical Resistance Strain Gauge

Measurements of pressures and torques in rolling-mills are necessary to the calculation of efficient design and economic loading of the mills. In this instrument four independent amplifiers are incorporated, each provided with individual calibrating networks for use with not less than four resistance gauges, each of 2500 ohms resistance.

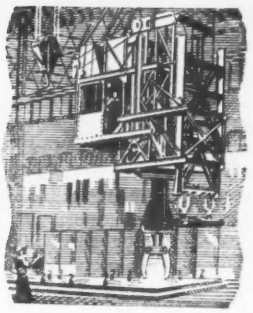
A stable oscillator provides a source of A.C. power for the Wheatstone bridges, and means are incorporated for balancing out the effects of long cables. The overall accuracy is $\pm$ 1% on pressure measurements and $\pm$ 3% on torque measurements. The amplifiers provide sufficient power to operate direct-writing high-speed chart recorders.

Plastic Replicas for the Examination of Metal Surfaces

A problem faced the B.I.S.R.A. South Wales Laboratories in their studies of roll surfaces in their work on surface geometry and coating conditions on steel sheets. Since it was impossible to transport stylus type profilometers to examine the rolls *in situ*, a method of taking a high fidelity replica had to be developed. That shown involves the polymerization of a thin film of a methyl methacrylate monomer-polymer mixture interposed between the metal and suitable sized pieces of transparent Perspex sheet. The replicas so formed are readily removed from, and reproduce with high fidelity, the contours of the metal surface. They are robust, permanent and suitable for direct examination on a stylus surface-finish measuring instrument. They are also suitable for the microscopic metallurgical examination of specimens not easily examined *in situ* and can also be used as projection transparencies. A modification of the technique may be applicable to the preparation of electron microscope transparencies. A description of the method and its applications was given in the *Journal of The Iron and Steel Institute*, 1948, vol. 159, May, pp. 67–70.

IRON AND STEELWORKS ENGINEERING

THE IRON AND STEEL ENGINEERS GROUP



The Design and Operation of Annealing Plant for Mild-Steel Sheets and Coils

By R. D. Pollard, H. Edwards, J. F. R. Jones, and J. Bromley Davis

SYNOPSIS

Part I deals with metallurgical considerations of the annealing of mild-steel sheets and coils. The general principles of annealing are outlined, and such terms as stretcher strains, grain growth, strain ageing, quench ageing, and earing, are explained.

In Part II particular attention is given to modern developments in equipment and practice, as applied to the annealing of mild-steel sheets. A new semi-direct-fired radiant-tube furnace is described, and the influence on annealing practice of such factors as rolling oils, atmosphere gas, and metal surfaces, is discussed.

Part III is devoted to the annealing of mild-steel coils in gas-fired and electric-pot furnaces and portable-cover furnaces, with various modifications such as forced circulation and convectors. The practical and economic factors affecting the selection of a furnace for a given purpose, are considered.

Part I—METALLURGICAL ASPECTS OF ANNEALING

By R. D. Pollard, A.Met., F.I.M.

GENERAL CONSIDERATIONS

ALTHOUGH strictly not within the province of engineering, it is considered that a brief review of some of the main metallurgical factors affecting the production and subsequent usage of mild-steel sheet and strip, will not be out of place.

Properties of Mild Steel for Sheets and Coils

Most of the mild steel used for the production of sheets and coils is the rimmed or silicon trace type, primarily because of its deep-drawing and pressing properties. Fully killed silicon solid steel of similar analysis has a higher rate of work hardening, but it is sometimes specified, even where deep drawing is involved, if the final product is to be case-hardened.

Generally, the steel (particularly if in the lower carbon ranges) is initially cold rolled direct in the hot-rolled condition. Apart from considerations of economy, only slight reduction in hardness and tensile strength would be gained from a preliminary anneal, and the risk of critical grain growth is eliminated by further cold working which will take the material beyond the critical reduction stage before the first annealing takes place. Where mild steels have to be rolled to specific intermediate tempers, it is usual to give an initial cold rolling direct from the hot-rolled stock, first to produce the desired surface finish, and then to anneal at a predetermined size, in order to arrive at the correct physical properties in the final size. If the finished product is required in the annealed condition, normal practice is again to cold roll direct to size from the hot-rolled strip and then to finish with a final anneal. An inter-annealing may be necessary when very thin sizes are involved.

The following are the physical properties that may be expected from the various tempers of low-carbon mild-steel sheet and strip used in this country, under their trade definitions:

Temper	Max. Stress, tons sq. in.	D.P.N. Hardness
Hard	Over 36	Over 165
Half hard	30–36	130–165
Quarter hard	25–30	105–130
Pinch passed or skin rolled	22–26	100–115
Annealed	20–25	80–100

Of these grades, the hard temper will usually be rolled direct from the hot-rolled condition, and the remainder will be given either an intermediate or a final annealing.

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Mr. Pollard is at Messrs. Samuel Fox and Co., Ltd., Stocksbridge Works, near Sheffield.

Objects of Annealing

The objects of annealing are twofold : (i) To obtain a spheroidized condition of the carbides as quickly as possible, particularly with the higher-carbon steels, and (ii) to remove the effects of previous cold working ; and in the case of mild and dead soft steels, to produce a suitably recrystallized grain size, either to facilitate further cold reduction or to give the maximum deep-drawing and forming properties.

The effect of cold working is to increase the rate at which spheroidization proceeds at suitable temperatures ; on reheating, the cold-work hardness is removed when a temperature of approximately 600° C. is reached, but with normal annealing cycles it is not possible to produce any measurable degree of spheroidization at such a low temperature. This proceeds at a reasonable speed only in the region of 680–700° C., where the carbide solubility and diffusion in the α-iron become almost critically more rapid. This in turn suggests that with the recrystallization following cold-work removal, the unstable condition of the lattice structure, and possibly the increase in grain boundaries from the newly formed grains, all tend to promote an easier diffusion of the carbon. Whatever the explanation, the process proceeds much more rapidly than if the same treatment is given to hot-rolled material on which no cold reduction has been performed.

Open Annealing

Although perhaps applying more to the higher-carbon steels, the most effective way of producing a spheroidized structure is to take the steel just through the Ac_1 change point, soak, and then cool at a rate of 15–20° C./hr. to a temperature of approximately 650° C. before withdrawal from the furnace. This has been the practice for many years at the author's works for higher-carbon hot-rolled rods used for wire drawing. These are ' open annealed,' that is, annealed in a furnace without pots or containers, and by this means a perfectly spheroidized condition is obtained in a single anneal. This procedure resulted from some laboratory experiments carried out early in 1925, when investigating the effect of various gas atmospheres in relation to surface decarburization, and which yielded what was at that time one rather surprising effect. It was found that when using an oxidizing atmosphere capable of producing a relatively heavy scaling of the surface, at a temperature just above the carbon change point, not only did no annealing decarburization take place, but the decarburization resulting from the hot-rolling process was also practically eliminated. The inference was that the scaling rate had kept in advance of any mild decarburizing influence present. This was a marked improvement on previous practice, where pot annealing had been employed, using subcritical temperatures, which took several annealings and drawings to produce complete spheroidization, and where accidental exceeding of the change point resulted in severe decarburization. With open annealing and complete spheroidization in one hot-roll anneal, heavier initial draftings in cold working are possible, and as no further improvement in structure is necessary, all subsequent inter-anneals can be carried out at subcritical temperatures merely to remove cold-work effects. Such inter-anneals have, in any case, to be carried out at subcritical temperatures, as pots or containers are necessary to preserve the surface, and at the same time any risk of further decarburization has to be eliminated.

The open-annealing procedure cannot be applied to higher-carbon sheets or strip, since reduction of surface scale takes place at the confined interfaces, even when the exterior atmosphere is oxidizing, and this effect is accompanied by severe decarburization if the carbon change point is exceeded. Subcritical annealing temperatures must therefore be used throughout, and this naturally slows down the process of spheroidization, which will take several annealings and rollings before the ideal structure is obtained. This applies even when using a maximum permissible temperature setting on the controls, giving approximately 680–690° C. on the charge within the container.

With mild and dead soft carbon steels no hot-roll anneal is necessary, and as prior cold rolling accelerates spheroidization, the subcritical annealing that has to be employed is quite satisfactory with a well-controlled charge. Although it might be argued that in the case of mild and dead soft steels, some decarburization would not be serious for many purposes, its presence represents bad practice. Many specifications call for material to fairly narrow carbon limits, which are already difficult to meet in silicon trace steels, also when the critical point is exceeded there is a risk of grain coarsening in the outer chill zone where the carbon content and impurities tend to be lower than in the interior. A further serious factor when exceeding the critical point is the added risk of ' sticking ' or welding at the reduced interfaces.

STRETCHER STRAINS

Although a low-carbon steel in the fully annealed state represents the condition of maximum ductility, this is unfortunately not suitable for many deep-pressing and forming operations, owing to the formation of what were originally known as Lüders lines, but which are now more usually described as stretcher strains. This phenomenon gives rise to an uneven surface during pressing ; Fig. 1 is a typical example, the irregular markings being due to the peculiar property of annealed low-carbon steels of yielding abruptly and locally when the elastic limit is slightly exceeded. Plane surfaces subjected to relatively slight amounts of permanent deformation show the worst effects, whilst a continuance of cold working gradually exhausts the areas of undeformed metal until a more or less uniform surface is again restored. The mode of formation of stretcher strains is by localized slip of blocks or wedges of metal in shear, which produces a thinning and a difference in level in the position of the affected areas. As deformation proceeds, the cold work in the already deformed areas causes a stiffening of the metal in these positions, until they are stronger than the undeformed positions, at which point further markings develop in the latter regions. If cold working is then continued, the whole of the undeformed areas is finally eliminated, and a uniform surface is

Fig. 1—Stretcher - strain markings on annealed low-carbon mild - steel strip, stretched to just beyond the yield point × ¾ approx.

Fig. 2—Sample of mild-steel strip, cold-rolled to 8% reduction and annealed at 680° C. The 'orange peel' effect was obtained after stretching beyond the yield point × ¾ approx.

Fig. 3—Microstructures of a sample of mild-steel strip after small successive cold-rolling reductions. Samples were taken at each stage and then all finally annealed at 690° C. for 4 hr. at temperature × 100

(Analysis : 0·07 C, 0·41 Mn, trace Si, 0·036 S, 0·014 P, 0·13 Ni, 0·02 Cr)

[*Pollard*

[*To face p.* 80

produced, with a slight thinning of the section, resulting from the general elongation.

When the annealed sheet or strip is purposely given a slight amount of cold work, as an extra operation, the formation of stretcher strains can be prevented for a more or less temporary period in several ways. One method is to reduce by a small but definite amount of cold rolling—usually a reduction of 0·00025–0·00075 in., or, say, about 1% of the thickness. This is known as pinch passing, skin rolling, or temper rolling, and the small amount of cold work does not seriously affect the ductility of the metal when subjected to subsequent deep drawing. An alternative method of eliminating stretcher strains is to pass the annealed product through staggered rolls, the reverse bending imposed cold working the metal throughout its thickness, without any measurable reduction in section. This is known as roller levelling or stagger passing. A modification of the latter method, which is sometimes used on the thinner gauges of annealed strip, is to apply a definite front and back tension during the passage through well-staggered rolls ; this results in an extraordinary degree of deadness in the strip, which when deflected shows an almost total absence of elastic recovery.

Figure 4 shows the effect of slightly cold rolling annealed low-carbon steel strip, as obtained on an autographic stress/strain curve. The full line is characteristic of the annealed strip, and shows the suddenness with which yielding takes place, and the subsequent irregularities which occur with the uneven yielding of the metal during the period of the formation of the stretcher strains. The broken line represents the type of curve obtained after approximately 1% reduction by cold rolling, from which it will be seen that, whilst the yield point is slightly lowered, the sudden yield effect is entirely eliminated.

The small amounts of cold work involved in preventing stretcher strains have only a relatively temporary effect, and in general the less the amount of cold working after annealing, the quicker will the stretcher-strain markings reappear on ageing. For this reason a definite pinch or temper pass is more effective than roller levelling or stagger passing, as in the latter case no perceptible reduction in thickness takes place. The effect of pinch passing will usually last long enough to cover any reasonable stocking period, before the material is used on the presses, and some fabricators carry out roller levelling just prior to pressing, which solves the difficulty of ageing effects. Any increase in temperature over room temperature should be avoided as this has a marked influence in accelerating the return of stretcher-strain markings.

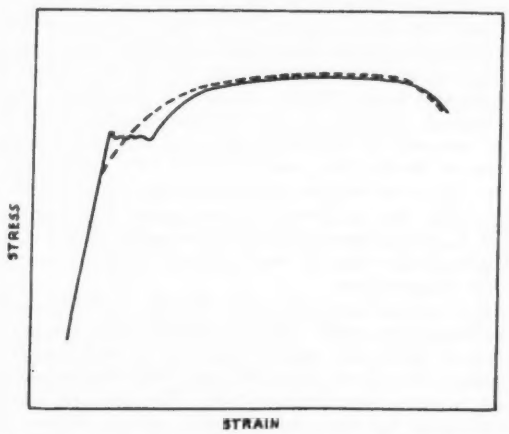


Fig. 4—Typical stress/strain curves for low-carbon mild-steel strip

Despite the small amount of cold working involved, the return of the stretcher-strain effect is due to a measure of strain ageing, and with the slightly heavier amount used in pinch passing, there can be both a slight increase in hardness, and a certain loss of ductility when the storage period is prolonged, from which it is obvious that the quicker the through-put of material which has been pinch passed or roller levelled, the less will be the risk of trouble arising in pressing.

GRAIN GROWTH

The problem of grain growth in low-carbon mild steel was at one time very serious, but the discovery that it arose from a critical amount of cold working has greatly simplified the position, and this trouble need no longer cause anxiety in sheet or strip production if a proper schedule of rolling and annealing is followed. Occasionally, however, a batch of light cold-rolled material may, by an oversight, be given a final annealing, in which case a coarse grain will be developed. This material, on subsequent forming, will exhibit the well-known ' orange peel ' effect which arises from the roughening of the surface due to the coarse grain size, when the steel is stretched in tension beyond its elastic limit. Figure 2, which is a photograph of a sample of mild steel deliberately given about 8% cold-rolling reduction, followed by a final anneal at 680° C., illustrates the ' orange peel ' effect.

A tentative theory of the cause of critical grain growth, is that with small amounts of cold work there are insufficient centres or nuclei of crystallization to produce any measurable influence on the size of the existing grains after annealing, but with critical intermediate reductions these nuclei are of such a number as to absorb adjacent grains quickly whilst readjustment is taking place during annealing. With still heavier reductions, nuclei are produced in such large numbers that, on annealing, there is more or less spontaneous recrystallization throughout the mass of metal, and the interference thus introduced prevents any but small or moderate-sized grains from being formed.

Increase in carbon content reduces the risk of grain growth, and with more than about 0·20% of carbon, it is more or less prevented, owing to the presence of carbide areas which obstruct grain expansion ; carbon diffusion in the α-iron will also have some influence, but to a lesser degree. Decarburization, on the other hand, promotes the tendency for grain growth to occur, even in the higher-carbon steels, where the decarburized layer will often exhibit a coarse columnar type of grain. Silicon trace steels also tend to show a rather coarser grain in the outer chill zone, due to the lower content

of carbon and impurities in this region, but with normal rolling procedures, the difference in grain size between chill and centre zones does not usually cause trouble from roughening in subsequent forming.

Various limits have been given to the critical range of cold reduction within which grain growth may be expected, and whilst this range is certainly affected by such factors as composition, annealing temperature, and decarburization, the methods adopted for cold working were in some cases capable of introducing a certain degree of inaccuracy. For this reason it may be of interest to give the results of a trial carried out purely on practical lines, but under as closely controlled conditions as possible, to determine the critical region of grain growth.

A coil of low-carbon mild-steel strip was cold rolled to 0·040 in. thickness, and slit to 1-in. widths, after which the coils were given a normal works anneal. The narrow width of 1 in. was used to obtain accurate control across the width in subsequent cold rolling, so reducing to a minimum any error in calculating the reductions. Duplicate small coils were then carefully rolled, aiming at 0·00025 in. for the first 0·001 in., and thereafter 0·001 in. up to just over 20% reduction. Every precaution was taken to avoid bending or deformation of any type on the samples, either after rolling or in the preparation of the test lengths. The latter were then annealed in the laboratory, using a dry hydrogen atmosphere to avoid both oxidation and surface decarburization. Two annealing temperatures were used, 690° C. representing normal annealing conditions, and 740° C. to study the effect of just exceeding the change point. Each annealing consisted of soaking for 4 hr. at temperature.

The microstructures shown in Fig. 3 are from one of the two 690° C. anneals and indicate the effect of annealing on the different small successive reductions involved. It will be seen that the change is very sudden from normal to the very coarse grain at about 9% reduction, after which the grain size becomes progressively smaller, until on approaching 20% reduction it is assuming reasonable proportions. The samples from the second coil annealed under the same conditions gave almost identical structures to those in Fig. 3, but the first sudden appearance of a very coarse grain took place one rolling pass earlier, at 6·4% reduction, showing how sensitive is the steel in this critical region. With the anneals at 740° C., both sets of samples gave results very similar to the 690° C. annealing as regards the actual grain size, which was little, if any, coarser at comparable stages of reduction. The first appearance of a very coarse grain occurred at reductions identical to those found in the 690° C. anneals.

On the evidence of this trial, it would appear that with an ordinary dead soft steel of the silicon trace type, the critical region for the coarsest grain growth approximates to a range of reduction of about 6 to 10%, whilst a relatively coarse grain persists up to about 16% reduction, this applying to conditions of annealing in normal practice and in the absence of decarburization.

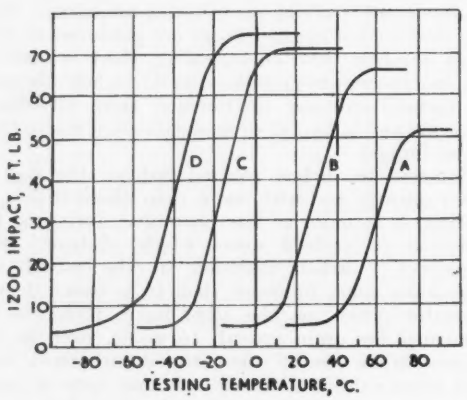


Fig. 5—Characteristic temperature/impact curves of strain-aged steels of differing susceptibility

STRAIN AGEING

Strain ageing is a rather unique property of low-carbon mild steel, that occurs when the metal has been subjected to a certain amount of cold deformation and is then allowed to age for a period. The result is an increase in hardness accompanied by a drastic reduction in ductility, as measured, for instance, by an impact test. Even a few per cent of cold-work reduction will produce some age hardening under favourable conditions, but the maximum effect, both as regards increase in hardness and loss of ductility, is reached with about 15% reduction by cold working.

The ageing effect proceeds very slowly at room temperature, and it may take several months to reach the maximum result under such conditions. An increase in temperature will accelerate the change to the extent that reheating to 300° C., for instance, will shorten the time interval to a few seconds. At higher temperatures the effect diminishes rapidly, softening setting in with a restoration of the impact value.

When testing for strain-ageing properties, the conditioning treatment usually adopted is to give a cold reduction of 15%, and then an ageing treatment of 30 min. at 250° C. The effect of such a treatment is remarkable, not so much for the increase in hardness which occurs, as for the very heavy loss in impact strength. The cold work alone causes some reduction in impact value, but this is only relative as no real embrittlement occurs at this stage. As a typical example, a low-carbon rimming steel in the normalized condition will give an Izod impact value of 80–90 ft.lb., and after the 15% cold reduction, the value will be reduced to about 65–75 ft.lb.; but when this is followed by the ageing treatment at 250° C., the values will drop to the region of 5–8 ft.lb. These results refer to tests carried out at a normal room temperature.

It is not always appreciated that the embrittlement resulting from strain ageing is related to the temperature at which the impact tests are carried out, this being very evident when the maximum change occurs round about room temperature. This perhaps is best illustrated by the characteristic curves shown in Fig. 5. Curve *A* represents a steel so susceptible to ageing as to give low impact values within the range

covered by any room-temperature fluctuations ; such steels also give lower maximum values at the higher temperatures. Curve *B* is of a rather less susceptible steel, which, however, will give very erratic results round about room temperature which are coincident with the steep portion of the curve. Curve *C* represents a steel which gives satisfactory values down to room temperature, but becomes embrittled at sub-zero temperatures ; and curve *D* is representative of a non-ageing mild steel, which has been strain aged, but treated with aluminium in steelmaking to yield a fine-grained condition and to inhibit strain-ageing effects. It will be seen that this treatment is effective for all normal temperatures of testing, but even here the characteristic form of the curve is maintained at still lower sub-zero temperatures. In annealed and strain-aged mild steels, the effect is to displace the curve still further to the right, when compared with a normalized and strain-aged steel of the same composition. Increases in phosphorous or nitrogen contents have the same effect, whilst nickel has an opposite influence in that a low-carbon steel with, say, 2% of nickel, even with an A.S.T.M. grain size of 2–3, will behave similarly to an inhibited fine-grained steel.

Various theories have been advanced on the cause of strain ageing, from strain set up in the slip planes resulting from submicroscopic recrystallization effects, to various precipitation-hardening theories involving one or more elements ; but, as far as the author is aware, no conclusive evidence on the fundamental cause of this phenomenon is as yet available.

The effects of strain ageing have necessitated considerable research into the field of non-ageing mild steels for pressing, and apart from treatment with aluminium, additions of both vanadium and titanium have been used for this purpose.

Pressings and formed parts, owing to the differential cold working involved, can develop serious brittleness in critically worked regions after a lapse of time if put into service either without a low-temperature annealing treatment or normalizing from 920° C., to recrystallize the structure entirely. Again, it will be evident that if pressings are merely formed, and then are subjected to hot-galvanizing, enamelling, stoving, or any other form of treatment likely to raise the temperature to between 200° and 300° C., there will be a definite risk of developing intense brittleness in critical regions. Many instances of failure due to this cause have been recorded.

QUENCH AGEING

When low-carbon steels and irons are quenched from a temperature just below the Ac_1 change point, they exhibit a tendency to increase in hardness, when allowed to age at room temperature ; this increase is progressive up to a period of time at which a maximum value is reached. Although these facts have been known for many years, it was left to later investigators to identify the cause as yet another example of precipitation hardening—a property which has since been developed and made use of in other alloys, particularly in the non-ferrous field.

That carbon has a limited solubility in α-iron was also recognized quite early on, from the fact that carbon diffusion was possible at subcritical temperatures, as in the process of carbide spheroidization, and later investigations have shown that the quench-ageing effect in mild steels is due to this limited solubility. The enforced solution of relatively small amounts of carbon, which occurs on the subcritical quenching, creates an unstable condition from which there is a gradual reprecipitation with the lapse of time, thus providing the necessary hardening phase.

There has been some slight difference of opinion as to the amount of carbon taken into solution at the maximum solubility point, which is around 720° C., but it appears to lie between 0·03 and 0·04%. There is also little doubt that the solubility at lower temperatures must diminish to a very low value, since below the region of 600° C. no perceptible spheroidization of carbide is possible with normal annealing cycles.

Whilst there are certain similarities between quench ageing and strain ageing, there are also marked differences ; for example, in quench ageing, the period for obtaining the maximum effect when ageing at room temperature, is in the region of four weeks, and this process cannot be accelerated by increasing the temperature, for this results in a lower hardness followed by an actual softening. On the other hand, cold working after quenching accelerates the ageing process, this feature being made use of in actual practice as, for instance, in the production of upholstery spring wire, where the cold drawing in itself can replace the prolonged ageing period. The following tests give an indication of the rate with which ageing proceeds at room temperature in a quenched mild-steel rod :

5g. Rod (C 0·10%, Mn 0·40%, Si trace), Water-Quenched from 700° C.

	Max. Stress, tons/sq. in.	Elong. on 2 in., %
Before quenching	26·2	39·0
After quenching	31·2	22·0
Aged 1 week	35·5	19·0
Aged 2 weeks	36·4	16·0
Aged 3 weeks	40·4	17·0
Aged 4 weeks	41·8	18·0

This material can be drawn into spring wire after quenching, to tensile strengths of approximately 70–80 tons/sq. in., either with or without the ageing period, which is rather remarkable for mild steel.

In general, the lower-carbon steels within the range 0·04–0·12% of carbon, give the maximum results on quench ageing, any increase beyond this range yielding a progressively less ageing effect.

The quench-ageing effect can sometimes become a source of trouble, as, for example, in salt-bath annealing. In this case the usual procedure is to remove the cold work by soaking in the bath for 20 min. at a temperature of 700° C. and then to withdraw the charge and allow it to cool for a period in air, before water quenching to blast off the adherent salt. If the charge is quenched too soon after withdrawal, all the conditions for quench ageing will be present.

An experience of this type on the plant with which the author is associated, yielded some rather interesting results. On the introduction of a salt bath for wire

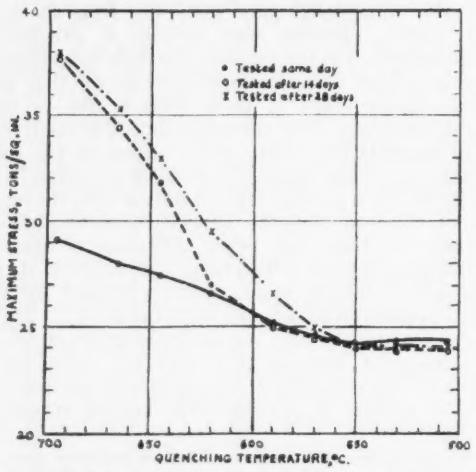


Fig. 6—Effect on low-carbon mild steel of quench ageing with a progressive reduction in quenching temperature after first soaking at a solution temperature of 695° C.

annealing, some low-carbon wire was given an inter-anneal in it before final drawing, which should have resulted in a drawn tensile strength of 35–40 tons/sq. in. It was found, however, that marked variations existed within the finished coils covering a tensile range of 35–70 tons/sq. in., and although the coils had been cooled to a dull red heat before quenching, quench ageing appeared to be the only possible explanation, not overlooking the possibility of the insides of the coils being at a higher temperature than the visible exteriors.

In view of this experience a trial was carried out on the effect of cooling to various temperatures before quenching. Suitable test lengths were cut from a coil of 0·148-in. dia. mild-steel wire, and were heated together in a laboratory furnace to 695° C., at which stage three lengths were withdrawn and water-quenched. The temperature of the furnace was then dropped by automatic control by 20–30° C., and the next three samples were withdrawn and quenched. This procedure was repeated down to a temperature of approximately 500° C., the total time allowed for reaching equilibrium between each withdrawal being 20–25 min. One set of samples for each temperature was then tested on the day they were quenched, a second set was aged for 14 days, and a third set for 28 days, before testing. The tensile results are shown in graphical form in Fig. 6, which indicates the change of maximum stress with progressively reduced quenching temperature. These results show quite definitely that the ageing effect does not revert quickly after cooling from 695° C., but that it diminishes progressively down to a temperature of approximately 550° C., and in practice therefore it is necessary to cool at least to this temperature, as with air cooling the ageing effect may be depressed to somewhat lower temperatures.

Although these comments are confined to wire annealing, and salt baths are not normally used for mild-steel strip annealing, the foregoing details appear to be worth recording, as with any process involving quenching from subcritical temperatures, the same factors would have to be taken into account, whether the material was in the form of sheets, strip, or pressings.

EARING

It is well known that both ferrous and non-ferrous metals can, and often do, show evidence of directional properties when cold rolled into strip form, and what is perhaps more unfortunate, this effect, when it is present, persists after final annealing. A great deal of thought has been given to this subject, and much experimental work has been carried out, not only for its academical interest, but also because such directional properties are very undesirable in a practical sense.

When strip possessing these directional properties is blanked and formed into cup-type pressings, it will not show an even edge at the mouth of the cup, but will have a wavy appearance, usually consisting of four lugs or 'ears,' these being normally disposed in geometric positions either at 45° or alternatively at 0° and 90° to the direction of rolling. Where the edge of the cup has to be trimmed, the presence of the ears may not be serious, but in many cases, particularly in the mass production of small cups, the extra operation is economically impossible, and a flat edge must be obtained in the as-pressed condition.

Some investigators have examined this problem from the standpoint of tensile tests, taken at various angles to the direction of rolling, and have found small but definite differences in properties, which in part explain why ears are formed. In annealed strip showing directionality, these tensile tests have shown the lowest maximum stress values and the highest elongation figures, in the positions in which the ears are formed. In the non-ferrous field the presence of earing and the magnitude of the effect, have been found to be definitely related to the cold-rolling reductions involved, and the influence of prior and final annealing temperatures.

In the manufacture of cycle chains, the barrels of the individual links, which have to resist the frictional wear of the sprocket teeth, are usually made from low-carbon (0·09–0·12% C) mild-steel strip, of the

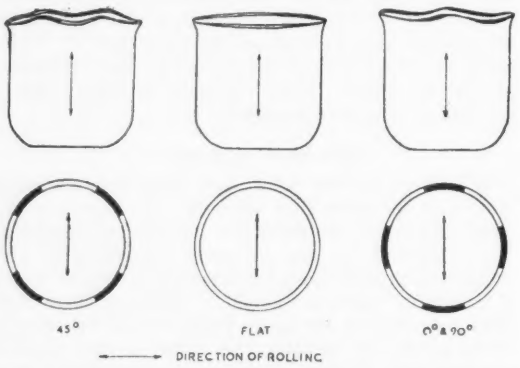


Fig. 7—Diagrammatic representation of the sequence of changes with increasing amounts of cold reduction. Effect on the directional properties of low-carbon mild steel and its earing tendency

silicon solid type, being finally case-hardened. The general method of manufacture is to produce the barrels by blanking circular discs from the strip, and cupping these in several stages, and then removing the base by punching. This bottom edge, by virtue of the method of production, has a flat edge surface, but the top edge, being free, will exhibit the characteristic earing effect if the annealed strip possesses directional properties. Experience had shown that earing varied in intensity from batch to batch of strip produced, and it was for this reason that an investigation became necessary. The work was carried out as far back as 1935, but for various reasons the results have not previously been published.

The first trial consisted of direct-rolling a coil of hot-rolled strip, and sampling at approximately 5% reductions in the cold rolling. The test lengths were then annealed, and cupping tests were carried out on a small press. This revealed the interesting feature that, with the lower cold reductions, earing was present at 45° to the direction of rolling ; with intermediate reductions the ears diminished until level tops were produced at about 25–28% reduction ; and with still heavier reductions the earing gradually developed in intensity again, but this time in 0° and 90° positions, as shown in Fig. 7. To ensure that these results were not fortuitous, the trial was repeated, and the cycle of changes was confirmed.

Bright normalizing the finished strip from 920° C. eliminates all directional properties which give rise to earing, but a continuous process of this type is both slow and costly. The possibility of producing level tops by a controlled degree of cold rolling, and with an ordinary final batch annealing, was therefore the better proposition. To obtain further data in regard to the effect of cold rolling, annealing, and then re-rolling, further coils were processed, this time starting with normalized strip, to eliminate any variables such as might arise from differences in finishing temperature and structure. All test samples were finally annealed before cupping tests were performed. Details of the tests and the results were as follows :

Coil No. 1—28% reduction in cold rolling, annealed, and then cold rolled a total of 60% reduction in 5% steps. The object was to see whether, after cold rolling to a state where level tops are produced, re-rolling repeated the cycle and caused the steel to behave as it would when originally cold rolled from the normalized condition. The cupping tests showed this to be the case as level tops were produced at 25% reduction.

Coil No. 2—50% reduction in cold rolling, annealed, and then re-rolled as in No. 1. The object was to test the effect of first putting the strip into a condition producing ears at 0° and 90° positions, and then re-rolling. The behaviour of this coil was particularly interesting as level tops were produced at 15–20% reduction, but up to 15% reduction the ears were still in the 0° and 90° positions, only more marked in the 0° position with respect to the direction of rolling. After the 15–20% reduction, 0° and 90° ears again developed with the heavier reductions.

Coil No. 3—Normalized, annealed, and then rolled 60% in 5% steps as a variant to the original tests on straight rolling from the normalized coil. Cupping tests again confirmed level tops at about 25% reduction, showing that both normalized and annealed structures produce the same cycle of changes.

Coil No. 2 appears to show that where strip is put into a condition to give ears at 0° and 90° positions by prior cold rolling and annealing, on re-rolling, this effect is gradually neutralized by an underlying tendency to produce ears at 45°, so that a stage is reached where the two influences cancel out and level tops are produced, after which the 0° and 90° positions of earing again reassert themselves. An examination of normal samples, as produced, for example, in coil No. 3, shows that in the production of level tops at 25% reduction, approximately the first 15% reduction is taken up in producing ears at 45° positions, and the next stage, up to about 25% reduction, is where the tendency for earing in 0° and 90° positions commences, the two effects cancelling out at around the 25% reduction, beyond which 0° and 90° ears gradually become evident.

The practical significance of these tests is that, by trial combinations of rollings, absence of earing can be achieved. For instance, rolling in 25% reductions between annealings, or with a heavier initial reduction of 50%, after annealing a further 15–20% reduction, will give the desired result. It has to be borne in mind, however, that the trials were on a silicon solid steel, hot rolled on a fast mill, and conditions might alter somewhat for other compositions of mild steel. It was found that there was little difference in reaction to the earing tendency between hot-rolled and normalized strip from this mill, as the finishing temperature was above the Ac_3 point. On a slow hot mill known to produce strip with a cold finish, it was found that this cold finish upset the normal position for obtaining level tops and displaced it upwards to about 40% reduction. There was, however, evidence that the product from any one hot mill behaved with reasonable consistency, although a fast mill with a high finishing temperature would be expected to show less variation from coil to coil, and such was the experience in the present trials.

Acknowledgments

The author wishes to express his thanks to the Directors of Messrs. Samuel Fox and Co., Ltd., and in particular to Mr. G. R. Bolsover, Technical Director, for permission to publish this paper. He also wishes to acknowledge the willing assistance of the staff of the Research Department of Messrs. Samuel Fox and Co., Ltd., in the preparation of the photographs and diagrams.

Part II—DEVELOPMENTS IN ANNEALING EQUIPMENT AND PRACTICE

By H. Edwards, F.R.I.C., F.I.M., A.M.I.Chem.E., and J. F. R. Jones, A.M.I.Mech.E.

In recent years the fixed furnace has largely been superseded by the portable-cover furnace for the annealing of mild-steel sheets. The portable-cover furnace, with its associated bases, enables larger tonnages of sheets to be annealed, under one furnace, since only the cover has to be handled. The origin of the furnace is closely connected with the process of low-temperature annealing of cold-reduced mild-steel sheets[1] and with the improvements in physical and surface characteristics which were essential to meet the challenge of the modern pressing technique.

The developments which have taken place at the Shotton Works of Messrs. John Summers and Sons, Ltd., will serve to illustrate general improvements, both in annealing furnaces and in annealing equipment. The original annealing furnaces associated with the 2-high hand mills were coal-fired dead-end furnaces, later replaced by gas-fired dead-end furnaces and tunnel furnaces.

Metallurgical considerations to meet trade requirements resulted in the development of the sheet normalizing furnace, and in improvements in the fixed annealing furnace. To deal with the product of the new 60-in. strip mill which commenced operations in 1939, the more modern portable furnaces were built.

The original installation of new finishing equipment to balance the production of the 3-stand 56-in. cold-reduction mill, estimated at 5000 tons/week, and the existing annealing plant, included 15 radiant-tube furnaces, with an estimated capacity of 2800 tons/week. A typical radiant-tube furnace, with a base 268 × 92 in., heated with clean producer gas burnt in 28 parabolic radiant tubes on each side, is shown in Fig. 9; up to 120 tons of sheets can be packed. Operational experience indicated that a number of improvements in connection with ventilation, buildings, furnace design, material flow lines, handling equipment, and instrumentation, should be incorporated in the planning of subsequent annealing equipment.

In 1946 a new 80-in. reversing cold-reduction mill[2] was installed, contributing 2000 tons/week to the existing 5000 tons/week, and an additional stand increased the capacity of the original 3-stand cold-reduction mill. The 8000 tons/week potential of cold-reduced steel sheets demanded a considerable increase

Mr. Edwards and Mr. Jones are at Messrs. John Summers and Sons, Ltd., Hawarden Bridge Steelworks, Shotton, Chester.

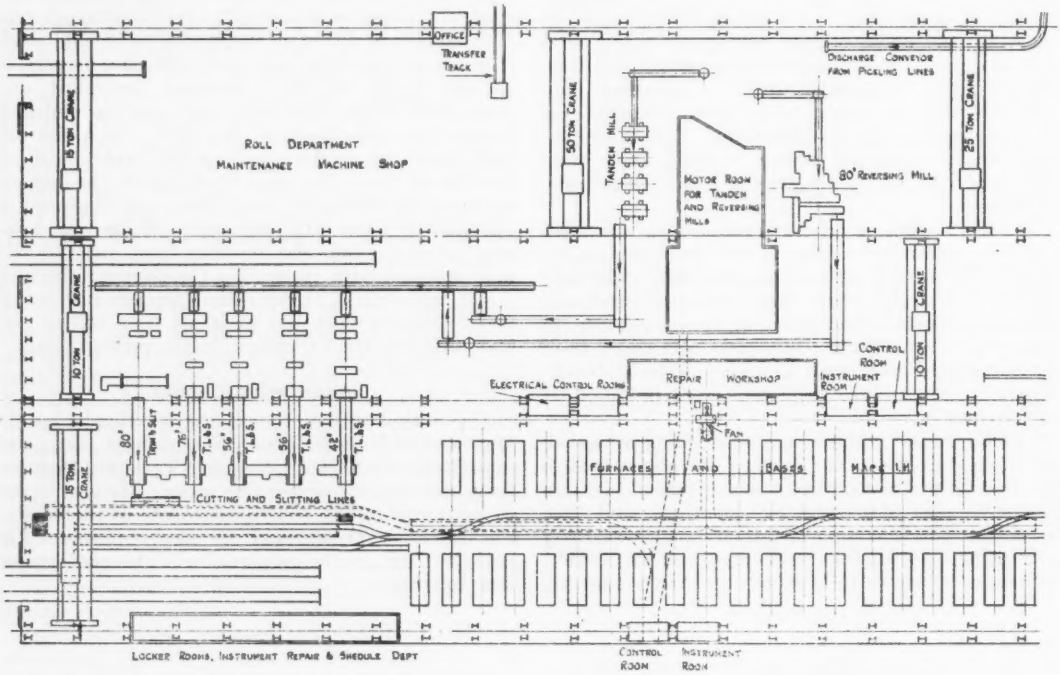


Fig. 8—Layout of annealing furnaces, cold-

in the capacity of the shear, anneal, temper, oiling, and miscellaneous equipment.

The ultimate design of the annealing furnaces was influenced by the following factors :

(1) Improvement in thermal efficiency
(2) Reduction in overall time to deal with deep-drawing material
(3) Easy convertibility of furnace bases to take either sheets or coils
(4) Prevention of space contamination by waste gases
(5) Elimination of noise from burners
(6) Utilization of waste gases for space heating.

Factors additional to those of mechanical and electrical design, such as administration and control, demanded consideration and collaboration at an early stage between production management and design and construction engineers so as to avoid uneconomical or unbalanced operations.

It was finally decided to build 11 additional furnaces, thereby increasing the production to 5600 tons/week.

THE ANNEAL BUILDING

The anneal building (Fig. 8) houses 26 furnaces with 81 bases ; it is 1050 ft. long, with a 100-ft. crane span, and is fitted with a continuous-ridge type ventilator. Fresh air is admitted along the whole length of one side, 5 ft. above floor level, through adjustable air flaps. The building is sheeted with bitumen-covered sheets, and is glazed in the roof to provide about 10% of glass to floor area. Cleaning walkways are fitted in the roof.

Supply of Material—The coils from the cold-reduction mill are either side-sheared and cut to length into sheets on the trim, level, and shear lines, or they are trimmed and recoiled on a trimming and slitting line for annealing as coils. The shearing lines also transfer the material into the annealing department.

Cranes—Handling is performed by two 50-ton cranes, each with 20-ton auxiliary hoists, and two 15-ton cranes, augmented with a floor rail system. Details of the crane speeds are as follows :

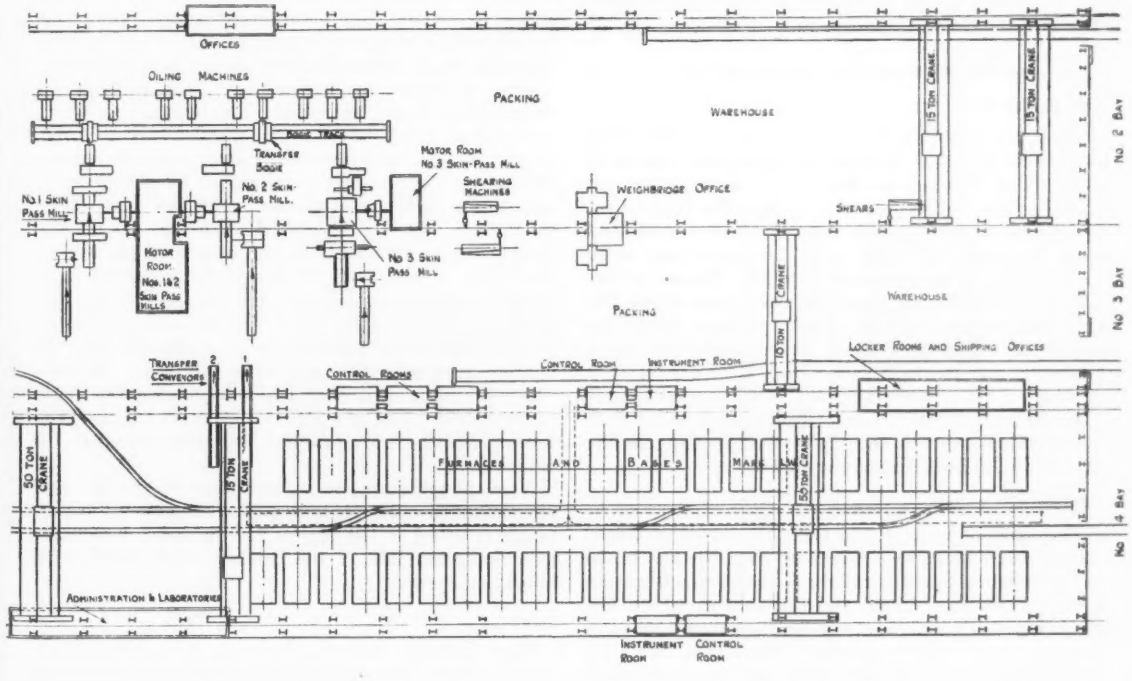
Crane Speeds, ft./min.

	50-Ton/20-Ton Cranes	15-Ton Cranes
Main hoist	15	30
Aux. hoist	32	...
Cross travel	130	150
Long travel	250	300

Floor Rail System—The floor rail system (Fig. 8) is serviced with six transfer wagons (Fig. 12) with flat tops, each of 50 tons' capacity, 11½ tons in weight, 25 ft. long, and 5 ft. 9 in. wide. The underframe is built up of rolled steel channels of welded construction, with ½-in. floor plates, strengthened by 56-lb. bridge rails across the wagon. The wagon bodies are of welded construction. Laminated springs support the wagon on the axle boxes, which have roller bearings. Automatic centre couplers are fitted.

The double track is approximately 1000 ft. long, of 30-in. gauge, and has 13 turn-outs of 50-ft. radius.

Each of the 6-ton battery locomotives has a drawbar pull of 1500 lb. at 4½ m.p.h., and is fitted with hand brakes. The wheel base is 49 in., the overall length 11 ft. 6⅛ in., and the overall height 51 in. Each locomotive has two 10-h.p., 120-V., series-wound



reduction mills, and finishing equipment

motors, 5-speed drum-type reversing controllers, spring-mounted buffers, and batteries of 450 amp.-hr. capacity at the 5-hr. rate.

A battery-charging station is situated near the rail system.

MATERIAL MOVEMENT

The sheets from the shearing lines are loaded by crane on to the transfer wagon for transfer to the appropriate base for packing. Because of the existence of the floor transport, cranes are used mainly for cross-travelling and lifting. The material is moved underneath cranes, to stripping bases, or discharging wagons, without interference to crane operations. The coils are discharged from the trimming line on to a conveyor leading to an up-ender, from which the coils are conveyed by magnet or lifting tongs to the transfer wagon. The double track with loops allows wagons to pass stationary wagons that are discharging or loading. After annealing, the material is moved to the storage area in the adjacent building ahead of the temper mills, levellers, and inspection, by conveyor or by the transfer wagon by way of the loop line. To give flexibility of handling, it is convenient in certain circumstances, especially where the crane run is short, to handle coils or lifts direct to the bases or conveyors. Rail and road access is arranged at both ends of the building.

The movement of material is handled by a production and schedule department, with a subsidiary section by the trim and shear lines for shear schedules and weighing prior to transfer to the anneal bases. The central office controls the movement through the furnaces and the ultimate transfer to the temper mills and finishing processes.

NEW ANNEALING EQUIPMENT

Anneal Bases

Three bases per furnace, or a total of thirty-three bases, were provided, with provision for four additional bases. The foundations, flues, etc., were laid out so that the bases were mutually convertible from sheet to coil and *vice versa*. The sheet bases are single steel trays supported on joists with the central pan lined with insulating and refractory brick. Plates on the top of this brickwork form the base upon which the actual sheets are stacked. Each coil base takes four stacks of coils, each stack being supported on a hematite iron frame within which is incorporated a circulating fan, driven by a 3-h.p. 970-r.p.m. motor, situated in a pit (Fig. 10*a*). A gland is fitted to each motor shaft between the motor and the impeller to prevent leakage of the atmosphere gas.

Furnaces

The general principles of the new semi-direct-fired radiant-tube furnaces, shown in Fig. 10, are based on the substitution of parabolic tubes by a combustion tube, terminating inside the furnace, in which the gas is burnt, the hot waste gases discharging into the furnace cover. Heat transfer is thus achieved both by radiation from the hot tubes and by convection from the hot waste gases. Greater use is made of burnt gases than in the full parabolic principle, and cover destruction may be less than with the open-flame design. The gas and air are burnt in the lower end of nickel–chromium tubes, about 4 ft. long, inside the furnace ; the gases exhaust from the upper ends into the furnace proper, being finally exhausted through nickel–chromium exhaust ports in the furnace bases. These ports deliver the gas into underground flues in the foundations. The flues are connected through valve-type dampers on each base to a common waste-gas flue from which the exhaust gases are discharged by fan to the atmosphere.

The extractor fan, which has a 30-h.p. motor, was designed to deal with 22,000 cu. ft./min. at 1·5 in. W.G., with a limiting temperature of 260° C. controlled by bleeding air into the flue system. It is proposed to utilize the waste gases for preheating air for space heating.

The overall dimensions of each furnace are 28 ft. 9 in. long, 11 ft. 8½ in. wide, and 15 ft. 7½ in. high. They are lined with 9 in. of insulating firebrick, backed by 1½ in. of slab insulation. On the sheet furnaces there are 56 tubes, arranged down both the long sides ; the coil furnaces have an additional four tubes, *i.e.*, two in each end.

The maximum gas flow to a sheet furnace is of the order of 32,000 cu. ft./hr. Each furnace carries its own individual air fan which is designed to have as flat a pressure/volume characteristic as possible so as to facilitate air/gas ratio control.

The temperature of the heating tubes and a selected steel temperature are limited by a potentiometer controller operating butterfly valves in the gas and air lines through suitable linkages. Earlier furnaces of the radiant-tube type were fitted with plug-type valves, but these were unsatisfactory as the slightest amount of dirt in the gas caused seizure. Butterfly-type valves have overcome this problem.

Dual pressure-type burners (Fig. 13), suitable for clean producer gas, are fitted. The burner consists of a cast-iron head, with a gas nozzle, mixing tube, burner nozzle, and secondary-air regulating screw. The primary-air supply is regulated by gas pressure and orifice plate and it passes round the sides of the gas nozzle where it is mixed with the gas in the mixing tube and fired from the nozzle on the end of the tube. About 80% of the air for combustion is supplied as primary air and the balance is adjusted by the secondary-air screw. The gas and air supply to all burners is automatically controlled by the charge temperature, operating through thermocouples and a controller which regulates the main control valves on the gas and air supply mains. The burner nozzles are arranged for easy removal for cleaning.

Vertical pressure gauges are fitted to the gas and air mains on each furnace and an inclined pressure gauge is fitted to the end of the furnace. There are two explosion lids in the furnace roof, fitted with operating levers.

Fuel

Blast-furnace and/or coke-oven gas, town's gas, and producer gas are commonly used, especially with portable furnaces. The furnaces at Shotton were originally fired with washed anthracite gas. Heavy

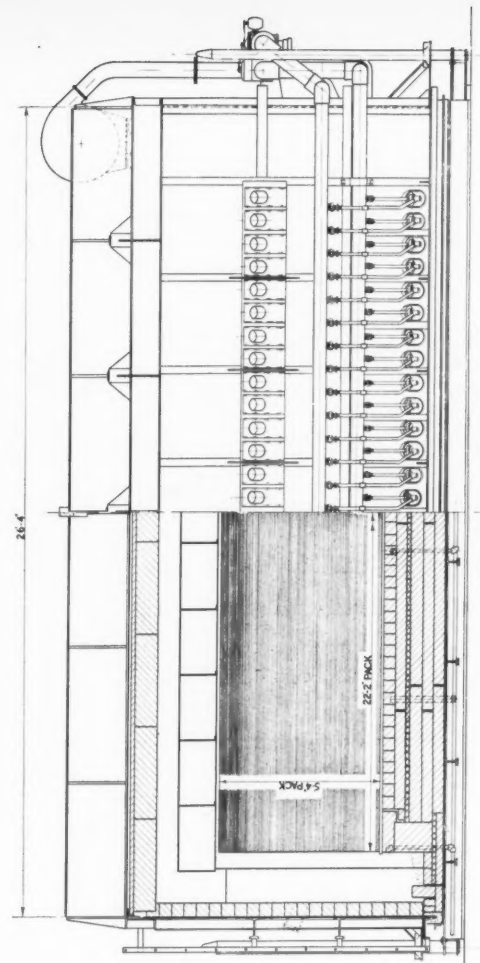


Fig. 9—Radiant-tube furnace for sheets

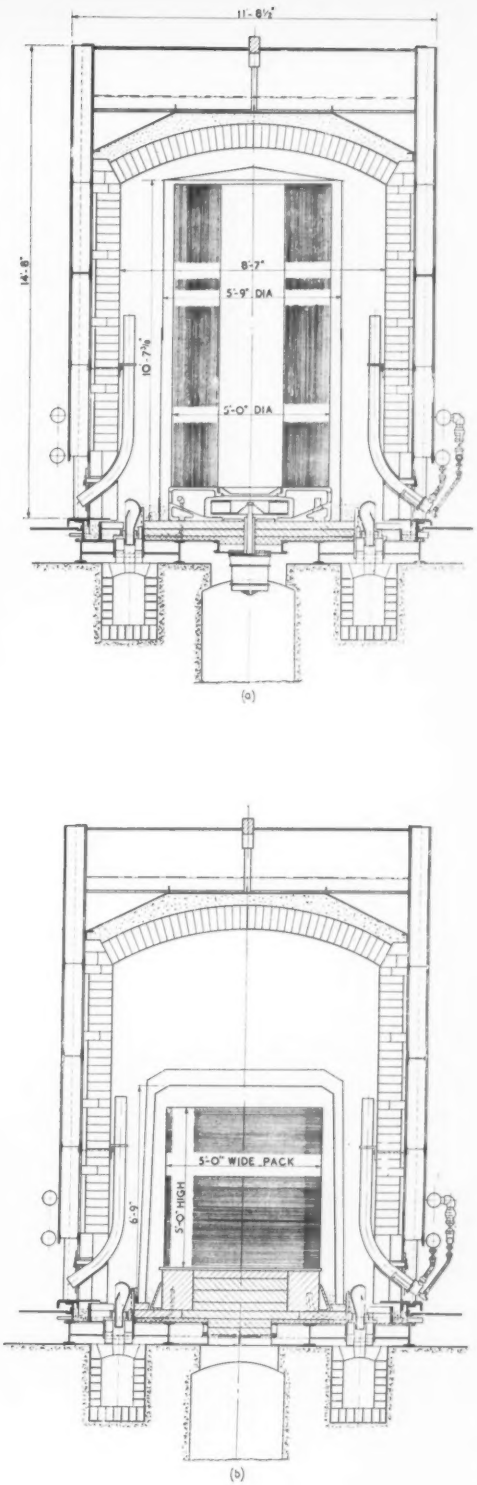


Fig. 10—Semi-direct-fired radiant-tube furnace for coils and sheets

[*Edwards and Jones*
[*To face p.* 88

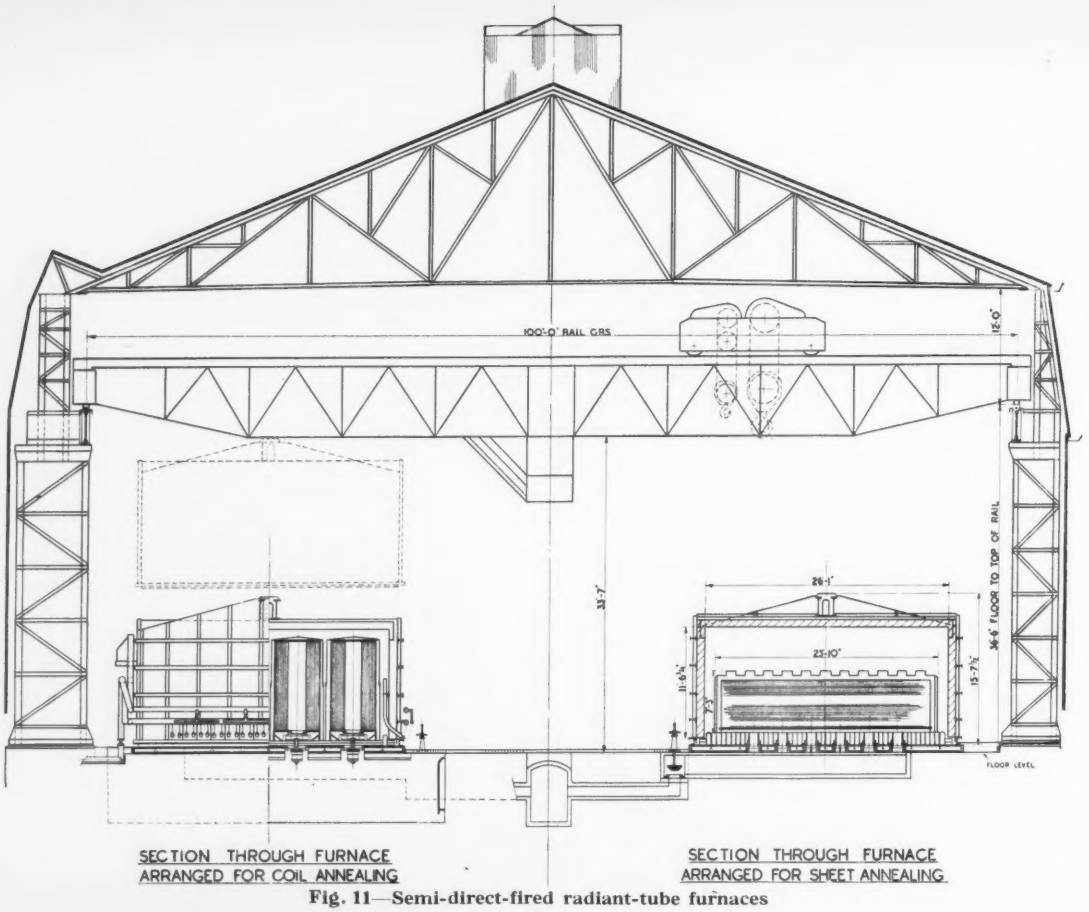


Fig. 11—Semi-direct-fired radiant-tube furnaces

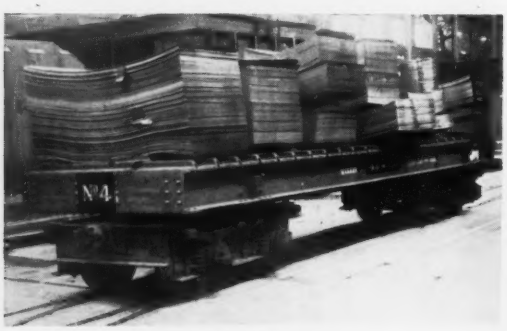


Fig. 12—Transfer wagon

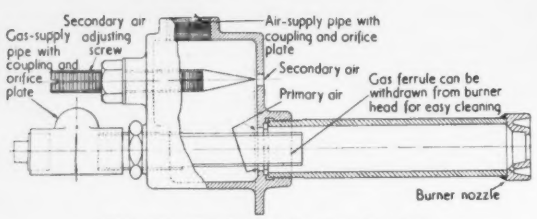

Secondary air
Gas-supply pipe with coupling and orifice plate
adjusting screw
Air-supply pipe with coupling and orifice plate
Secondary air
Primary air
Gas ferrule can be withdrawn from burner head for easy cleaning
Burner nozzle

Fig. 13—Radiant-tube gas burner

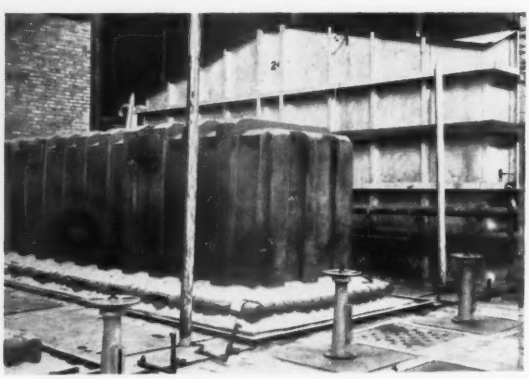


Fig. 14—Annealing furnace and inner cover

tar deposits in the pipes and valves were eliminated by the use of cleaned bituminous producer gas supplied by a battery of producers and washed and detarred by a cleaning unit with a capacity of cleaned gas of 400,000 cu. ft./hr., relatively free from tar, of the order of 0·01–0·02 g./cu. m. Any light oil which condenses in the system is easily removed. The cleaning equipment consists of a water tower to remove dust and heavy tar, disintegrators to eliminate fine droplets of tar, spray separator towers, a cooling tower, and electrofilter to remove droplets, dust, water droplets, mist-substances not in the gas phase, and gas boosters. Desulphurization is necessary for atmosphere gases.

Inner Covers

The inner cover, which is placed over the charge, is filled with a protective gas atmosphere and is subject to the action of the hot gases inside the furnace and the atmosphere gas at relatively high temperatures. The resulting deterioration, however, is due more to distortion and the failure of welds than to oxidation.

Although many designs and materials have been used, there is still need for a reliable inner cover. Rectangular covers with angular and circular corrugations in mild steel or heat-resisting steels are common types, and covers with heat-resisting steel frames, plated with renewable mild-steel plates, have been used. An annealing furnace and inner cover can be seen in Fig. 14; some conception of the life of an inner cover built from mild-steel plates $\frac{5}{16}$ in. thick, can be gained from the following figures:

Number of covers	65
Number of charges:	
Min.	40
Max.	117
Average	69
Tonnage:	
Min.	4147
Max.	12,887
Average	7512

Maintenance is a serious problem if large numbers of covers are used.

Furnace Operation

In operating a parabolic-tube furnace for annealing mild-steel sheets, the furnace base is covered with 1-in. mild-steel plates to give a level surface on which the sheets are packed. The thermocouples are fitted and the inner cover is placed over the charge. Before the furnace is positioned, the inner cover is purged by the admission of atmosphere gas under pressure. Eventually, the gases from the tell-tale exit pipes, which are fitted with gauzes, are lit. After the radiant-tube furnace is placed on the base, gas, power, and instrument connections are made, and the air and gas valves are set. The gas is turned into the parabolic tubes, and after lighting it at the top of the tubes, the air valve is opened and each tube is checked and adjusted.

With the new semi-direct-fired radiant-tube furnace, after the side-flue mushroom valves are opened the furnace is placed on the base and all connections are made. Each burner gas valve is opened in turn and the burner is lit through the spy-hole with a gas taper. The air is adjusted to give correct combustion.

In contrast to the former type, gas pockets—with explosion hazards—are impossible because of the suction inside the furnace. As the temperature of the charge rises, rolling-oil residues are burnt and volatilized and expelled under pressure from inside the inner cover, after which the exit pipe is partly closed. By control of the individual dampers, a slight positive pressure is maintained inside the furnace. Automatic control of the furnace pressure has been recommended. The furnace is controlled by a thermocouple situated inside the furnace between two tubes. When the side temperature is reached, steady conditions are maintained until the necessary base temperature within the charge is attained. The charge is then soaked for a predetermined period, after which the furnace is removed, and the charge cools under atmosphere-gas pressure.

The instrumentation is in four sections in each of which all recording potentiometers are wired through switch panels to each base; to meet congestion, instruments in adjacent sections are connected. The accuracy of heating is of great importance and is completely dependent upon the instrumentation. Hence fully equipped instrument repair rooms are provided, the cost of which is amply repaid by having accurate control of grain size and the prevention of sticking.

Operational troubles, such as process handling faults, should be studied to avoid damage to the surface.

The gas atmosphere needs careful control to prevent oxidized edges, and subsequent retreatment of the sheets.

Maintenance

The life of the portable-cover furnace with parabolic tubes compares favourably with that of the fixed furnace. Most deterioration of the parabolic tubes results from mis-shapen covers and the action of sulphur gases. Only after some six years has relining of the roof and walls been necessary, with a little patching of the steelwork. An assessment of the life of the semi-direct-fired furnace cannot be made until it has been in service for a longer period.

Repairs to furnace bases are extensive, and brickwork, plates, and purge pipes require constant attention to ensure a level and solid base for the sheets, and free passage of the purge gas.

The repairing of the inner covers is a serious problem, owing to the severe distortion of the plates. Minor welding is often necessary, and major repairs consist of the straightening or the replacement of badly shaped ends and sides. Triangular castings around the base foundation prevent the bottom edges of the covers from curling in.

Furnace Performance

Improved process time to meet delivery requirements is achieved with reduced furnace capacity helped by faster heating so that an 80-ton charge would nowadays be considered a more satisfactory unit. The larger 120-ton charge at a rate of 1 ton/hr. equals 5 days plus the cooling period of $3\frac{1}{2}$ days. In comparison, the 80-ton charge at an improved rate of 1·25 tons/hr. equals 2 days 16 hr. plus 3 days' cooling period—an improvement of 2 days 20 hr.—so that for this reason and the dual-purpose design

and convertibility factor of the furnace, it was decided to reduce the width of the furnace.

The semi-direct-fired radiant-tube furnace, compared with the parabolic radiant-tube furnace, has shown an improvement in speed of some 13% for deep-drawing sheets and 26% for the ordinary sheets.

It was considered that three bases would be sufficient to deal with the firing potential of one furnace. Operational experience has shown that, even with a firing cycle of 54 furnace-hr. plus 72 hr. to cool under the inner cover, with 36 hr. hold on the base to allow the sheets to be stripped without handling marks, three bases would barely be sufficient to accommodate one furnace. With a firing cycle of 40 furnace-hr. there would be a serious loss of furnace-hours. Obviously, the mixture of sheet grades, resulting in an output of 1 to 2 tons/hr., is a deciding factor in the calculation of base requirements. It has been recommended that some form of accelerated cooling should be used to reduce the cooling period and the hold on the base.

With the dead-end furnace, fuel consumption was of the order of 3,000,000 B.Th.U./ton of sheets, and 1,500,000 B.Th.U./ton for the original parabolic radiant-tube furnace.

The firing cycle influences considerably the fuel consumption so that it is essential to know the background of the performance. With a series of charges under similar conditions, running parallel, with the same material, a semi-direct-fired radiant-tube furnace used 1,000,000 B.Th.U./ton, compared with 1,250,000 for a radiant-tube furnace, an improvement of 20%.

INFLUENCE OF VARIOUS FACTORS ON ANNEALING PRACTICE

Although factors related to process treatment in the steelworks, hot-mill finishing, and cooling temperatures, and cold-reduction procedure, influence considerably the annealing practice, the less-known effects of rolling oils, atmosphere gas, and surface roughness, will be considered briefly.

Rolling Oils

The action of rolling oil as a lubricant and coolant on the cold-reduction mills, is directly related to surface contamination. It should be properly balanced so as to withstand extreme pressure and temperature during cold reduction and to prevent ' pick up.' There should be a minimum amount of oil residuals and abrasion products from the rolls and strip.

The percentage reduction of successive passes, the total reduction, and the method of application, govern, to a large extent, the composition of the rolling oil. Heavier strip produced by relatively light reductions of the order of 40 to 50%, is rolled successfully with non-soluble oils or with soluble oil emulsions. Lighter gauges with reductions up to 70% are best produced with non-soluble rolling oils containing fatty and chemical additives to stabilize the oil film under severe conditions. The additives are frequently benzine derivatives with nitro and halogen radicals added or substituted. The nature of the additive can be critical both in its first effect on surface finish and in its ultimate effect during annealing.

To determine the correct rolling oil, consideration must be given to the physical and chemical properties of the steel, mill conditions and reductions, and the surface condition required for subsequent treatment. Mineral oils, soluble oils, or even palm oil, are used.

Much of the oil residue is burnt or volatilized during the initial stages of annealing, and the removal of the superficial and embedded residual films is of much importance for subsequent surface treatment.

Effect of Gas Atmosphere

The metal surface is either oxidized or deoxidized. Oxidation is achieved by the use of an atmosphere gas for the initial stage of cooling, and by controlled infiltration of air during cooling to give a bluish oxidized surface. A deoxidized surface (previously obtained by treatment with acid) is achieved by atmosphere-gas protection during the annealing and cooling stages. The composition of the atmosphere gas has an important influence on the metal surface finish. Dissociated ammonia and burner gas, partially burnt and treated town's gas, and coke-oven and blast-furnace gases, giving the so-called *DX* or *NX* gases, are widely used. Typical compositions of the various gases are as follows:

	(1)	(2)	(3)	(4)	(5)
CO_2	12·0	0·2	4·0	5·8	...
O_2	0·0	0·0	0·0	0·0	...
CO	15·0	1·5	11·6	9·8	...
CH_4	1·0	0·0	0·7	0·05	...
H_2	5·0	1·2	14·8	11·0	75·0
N_2	67·0	97·1	68·9	72·0	25·0
S, grains/100 cu. ft.	30	...	< 5	...	...
Dew point, ° F. ...	< 30	...	...	40	...

(1) Treated bituminous producer gas
(2) *NX* gas
(3) Partially burnt town's gas[3]
(4) Partially burnt gas[4]
(5) Dissociated ammonia.

The authors have studied the treatment of cleaned bituminous producer gas by elimination of sulphur, partial combustion, washing, cooling, and drying, to give compositions similar to that shown in column (1). With this atmosphere gas a much improved surface finish was obtained. The gas should be relatively dry, free from oxygen, and have a sulphur content below 30 grains/100 cu. ft. If the sulphur is over 50 grains/100 cu. ft., a reasonable finish cannot be obtained, but there is a definite improvement if the gas is passed through cylinders filled with iron turnings situated inside the inner cover at the charge temperature. The explosion hazard is reduced with the use of partially burnt gas and especially with *NX* gas.

Effect of Surface Roughness

The roughness of the metal surface is dependent largely on the shot-blasted surface of the work rolls; in a tandem mill the rolls in the last stand have the greatest influence, and in a reversing mill the effect is cumulative.

Surface roughness is closely linked with the problem of sticking, especially in the case of sheets; hence annealing practice is influenced by the roll surface finish, by roll-changing procedure (since the surface wears with rolling), by the type of rolls, and by the rolling oils. One of the authors, in a study of surface roughness and annealing, has shown that below a mean average[5] of 35 μin., there is serious danger of sticking.

The surface roughness produced by cold reduction

is masked by the smoother finish of the temper mill, but nevertheless there is a relation with the finish of pressings. Surface coarsening occurs with a final roughness of 70 μin. It appears that suitable standards would be 50 μin. at the cold-reduction stage and 35 μin. for the tempered surface. The ultimate finish is a compromise between two limits; the work-roll finish before use, to achieve 40 μin., would have to be of the order of 170 μin.

Other factors in mill operation, such as the percentage cold reduction, influence the surface finish and should also receive consideration. Under rolling conditions, the wear of the rolls will reduce the strip roughness some 5 μin. during the rolling of 400 tons.

The surface finish of the two sides of the sheet should be similar.

Piling height, the shape of the material, dusting, temperature control, and distribution of heat, also influence the susceptibility to sticking.

OTHER FURNACE DEVELOPMENTS

Modifications of the original type of radiant-tube cover furnace include horizontal arrangements of the tubes, long vertical burner tubes passing through the roof, and recirculating radiant-tube type combustion units hung across the furnace, more especially for coils.

The direct-fired cover furnace in which the gas and air burn either on refractory tiles or in a baffle pocket, shows an increase in output with a reduction in fuel consumption. A furnace of this type[6] has been designed in which the burners are situated on the two longitudinal sides of the base, as distinct from the furnace. Metallic recuperators preheat the air for combustion, and the waste gases are removed from the building by a flue system.

Fixed in-and-out type furnaces which have been rebuilt at Shotton, are now direct-fired with clean anthracite producer gas. The burners on each furnace are arranged in banks down each side. Each bank of burners has its own separate gas and air supply from the main headers and is controlled by one gas valve and one air valve, both hand operated. Each burner has its own trimming valves. The flames from the burners are directed on to refractory slabs. Gases are exhausted through ports in the bottom of the furnace. The furnace bases are loaded on stillages situated on the opposite side of the building to the furnaces. Running between these stillages and the furnaces is a charging machine which can pick up a base from any stillage and transfer it into any furnace, or *vice versa*.

CONCLUSION

There is much interest at the present time in coil annealing because of advantages such as a reduced hazard of sticking, improved removal of rolling-oil residues, faster annealing cycles with forced circulation, reduced process costs, improved tonnage on the temper mills, and the elimination of end marks and other defects peculiar to the rolling of sheets. Owing to the unpredictable fluctuations in the demand for coils for shearing into sheets as a final mill operation, or shipment, it is important that furnaces should be easily convertible for the annealing of either sheets or coils.

Acknowledgments

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Part III—THE ANNEALING OF MILD-STEEL COILS

By J. Bromley Davis, M.A., A.M.I.Mech.E.

MILD-STEEL strip in coils is produced in a wide range of sizes; coils which are annealed range up to a maximum size of 78 in. outside dia. and 72 in. wide. The production of large coil sizes has various advantages over that of small sizes and hence there has been in recent years a rapid development in equipment for the annealing of large coils, although at present the largest sizes can be handled only in the U.S.A.

In the past, box-annealing has been largely carried out as a batch process in an in-and-out furnace, or as a continuous process in a bogie tunnel furnace. The annealing of mild-steel strip in coils, which is a more recent process, is today largely carried out in this country as a batch process in one of two types of furnace, the pot furnace or the portable-cover furnace. These two furnace types form the subject matter of this part of the paper.

For bright annealing, the charge must be heated in a protective atmosphere. In the early days this was achieved by packing the charge in cast-iron borings in a cast-iron or heavy fabricated steel container; today, the strip to be annealed is enclosed in a light fabricated steel cover within which is a protective gaseous atmosphere, as described in Part II of this paper.

POT FURNACES

Gas-Fired Furnaces

Grunewald pot furnaces for coil annealing consist essentially of a vertical cylindrical furnace chamber within which the charge is suspended, protected by a light steel container. A protective gaseous atmosphere is admitted to the charge.

Various gaseous fuels have been used to fire this type of furnace. A complete gas-fired furnace unit consists of three chambers, in each of which is suspended a charge, together with a cooling rack with

Mr. Bromley Davis is at the Research and Development Department of The United Steel Companies, Ltd., Sheffield.

positions for several charges. Combustion takes place in the first, or heating chamber ; the products of combustion pass from the first chamber to the second chamber, and then to the third chamber, preheating the charges in those chambers. When the charge in the first chamber has completed the heating cycle, it is removed to the cooling rack ; the charge in the second chamber is moved to the first chamber, the charge in the third chamber is moved to the second, and a new charge is placed in the third chamber.

The gas-fired furnace of this type has two disadvantages : (1) The maintenance cost is relatively high, and (2) the temperature field within the stock and the uniformity of results desired for certain types of work, cannot always be obtained.

Electric Furnaces

In the course of development of the pot furnace, electric resistance heating has been substituted for gas-firing. The temperature of the stock in the electrically heated pot furnace can be more accurately controlled, uniformity of results is obtained, and less maintenance is required.

The three chambers of the gas-fired furnace unit are replaced by a single heating chamber, round the periphery of which are arranged the resistance elements. This type of furnace has been described elsewhere.[3]

Up to five positions in the cooling rack are required for each electric furnace. Additionally, a recuperator unit may be installed between the furnace and the cooling rack, thus providing two more positions for each furnace. A layout of a battery of eight furnaces, with recuperators, is shown in Fig. 15. An advantage of the recuperator is that a saving of about 16% in the power consumption may be obtained by preheating the stock to be charged into the furnace ; this saving will be realized only if there is a steady throughput of material, as otherwise considerable heat losses from the recuperator will result. Another advantage may be obtained when the rolling oil has not been removed from the stock prior to annealing ; the preheating period in the recuperator permits some of the rolling oils to be volatilized and purged from the pot at a low temperature. If a relatively long heating cycle is employed, the number of positions in the cooling rack required for each furnace will be reduced and the recuperator may not yield any significant saving in power.

When a battery of electric furnaces is equipped with recuperators, the cycle of operations requires each charge to be lifted six times, apart from loading and unloading. This imposes a relatively heavy duty on the crane. When the shop width permits such an arrangement, it is as well to site the equipment so that the furnace, the two recuperator positions, and the five cooling-rack positions associated with it, are in line and traverse the shop. In this way the long-travel motion of the crane will be kept to a minimum, and all the movements relating to loading and unloading any one furnace can be dealt with by the cross-travel motion. This layout is shown diagrammatically in Fig. 15.

Electric furnaces are made in various sizes, to take coils from 27 in. to 52 in. outside dia., and a charge of up to 15 tons. A common size is a furnace designed to take coils up to 42 in. outside dia., stacked to a height of 48 in. The corresponding container will have a depth of 74 in. This furnace is designed to take a maximum charge weight of 4½ tons and to give an output of about 60 tons/week. The connected electrical load is 130 kW.

Electric furnaces have been operating for upwards of ten years and have given little or no trouble. All major components of this type of furnace have a more or less indefinite life.

The most vulnerable point in these furnaces is the contactor gear which, owing to the on/off type of control used, has a heavy duty. The contacts are liable to pitting and eventually to sticking. At one plant each set of contacts is inspected every 48 hr.

Attempts have been made to improve the performance of the pot furnace by employing the principle of forced circulation of the gases within the pot, which has been successfully applied in the portable-cover furnace and is considered in detail in the succeeding section. In Grunewald pot furnaces the only place for a circulating fan is just under the pot lid and immediately above the stack of coils ; the fan cannot be used to full advantage because the distance between the top of the stack and the pot lid varies, firstly, because the stacking height varies from charge to charge and, secondly, because of the expansion of the suspension bars during the heating cycle.

PORTABLE-COVER FURNACES

Since economic considerations make it imperative to utilize the more rapid heating that is possible with

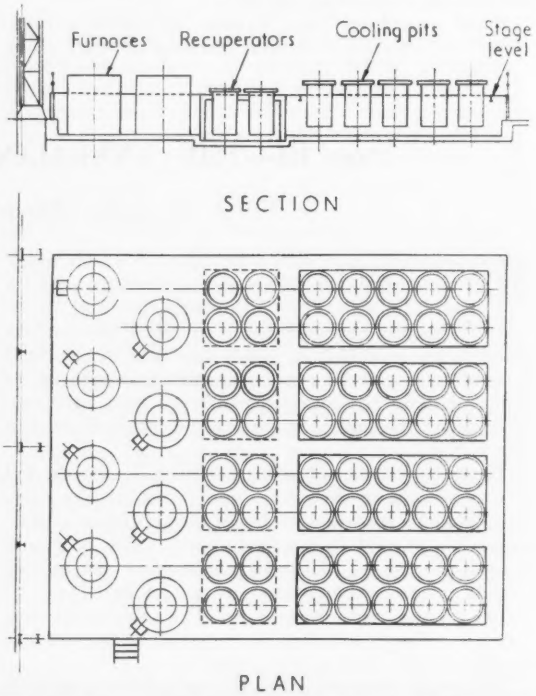


Fig. 15—Layout of battery of eight electric pot furnaces

forced circulation, large coils are normally treated in portable-cover furnaces. The development of this type of furnace has resolved certain disadvantages of the earlier gas-fired furnaces. The furnace itself and the inner cover that envelopes the stock to be heated, are portable. The coils to be heated are stacked on a pedestal on the furnace base and a light fabricated steel inner cover is placed over them. The furnace is then placed over the inner cover. Normally, each furnace is provided with three fixed bases, one loading, one heating, and one discharging, so that the furnace can be in constant operation.

The furnace is constructed of welded steel plate, supported and stiffened by structural steel members. The sides are lined with insulating refractory material. A sprung arch, suitably insulated, is used. With radiant-tube firing, the furnace brickwork requires relatively little maintenance and should have a life of more than six years. There is as yet insufficient experience to be able to assess furnace life under conditions of direct firing.

The portable-cover furnace may be circular or rectangular. The circular furnace has normally one inner cover, and may be used either for a single stack of large-diameter coils or for several stacks of small-diameter coils. In the latter case, the coil stacks are arranged round the periphery of the pedestal. The rectangular furnace has a base with two or more pedestals, each with its own inner cover; such a furnace is termed a multi-stack furnace and is used for relatively large outputs.

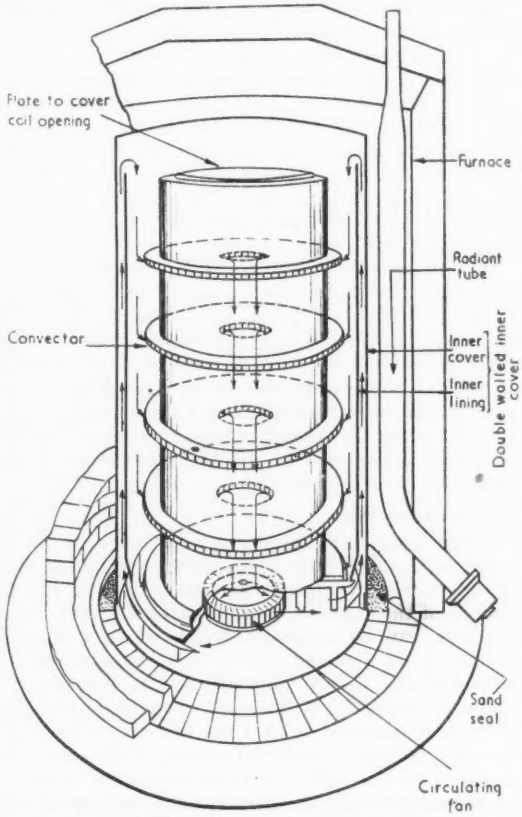


Fig. 16—Exploded view of convector furnace

The protective gaseous atmosphere is admitted to the inside of the inner cover through the furnace base. In order to retain the protective atmosphere the bottom edge of the inner cover beds into a seal around the pedestal. Sand is often used as a sealing medium and must be used in the rectangular furnace. In the circular furnace an inner-cover seal may be provided remote from the high-temperature zone, and, since sand seals always permit some leakage of the protective atmosphere, this type of furnace is often designed to have a liquid seal.

Methods of Firing

For economic reasons, portable-cover furnaces are normally gas fired, although oil firing or heating by electric resistance elements can be employed. The early furnaces were fitted with radiant-tube burners, and this is still common practice. The original type of radiant-tube element, and one which is still widely used, consists of a vertical heat-resisting alloy-steel tube secured to the side-wall of the furnace, as indicated diagrammatically in Fig. 16. A burner delivers fuel gas and air into the lower end of the tube, combustion is completed within the tube, and the products of combustion are vented outside the furnace. Another form of radiant-tube element is hairpin-shaped and is placed horizontally; it may be either slung along the side-wall of the furnace or, in the case of multi-stack furnaces, suspended so as to come between the stacks.

With the advent of radiant-tube firing, it was found possible to use mild-steel inner covers of lighter construction than had been used in the earlier direct-fired furnaces, because the scaling conditions were less severe. This permitted a reduction in fuel consumption and an increase in furnace output.

Radiant tubes are liable to fracture and to become perforated. Excessive tube failures have sometimes been caused through failure to make proper provision for expansion of the tube. In the case of the vertical tubes, an expansion device is provided at the upper end where the tube leaves the furnace, and the life of the hairpin tubes has been extended by suspending the tubes by hangers from the furnace roof instead of clipping them to the side-walls. The indications are that the use of a fuel gas with high sulphur content will result in a more rapid deterioration of radiant tubes than when a relatively sulphur-free gas is used. Experience with radiant tubes differs, but in general considerable maintenance is required.

Failure of a radiant tube may cause the atmosphere surrounding the inner cover to become more oxidizing, with an unfavourable effect on inner-cover life, particularly if it is made of unprotected mild steel. This in turn increases the cost of furnace maintenance.

Partly with a view to reducing maintenance cost, the modern direct-fired portable-cover furnace has been evolved to replace the radiant-tube furnace. Before direct-firing could become a practicable and economic proposition it was necessary to find a light inner cover that would give a tolerable life under the scaling conditions of the direct-fired furnace; this problem has now been resolved and is discussed later.

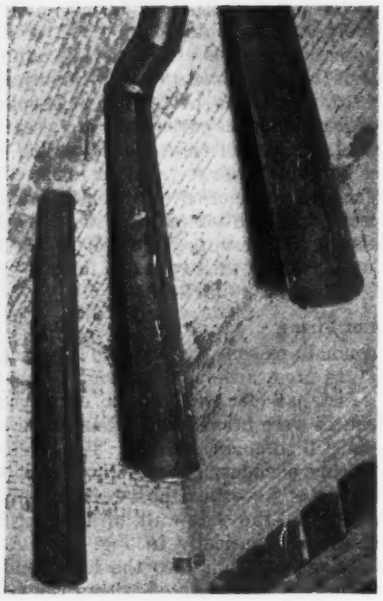


Fig. 17—Interior of 8-stack portable furnace, showing burner arrangement and heat-resisting steel vents

Experience with furnaces fitted with low-powered circulating fans, converted from radiant-tube to direct firing, indicates that direct firing has certain advantages : (1) Furnace output is increased by more than 10%, (2) fuel consumption is reduced by more than 15%, and (3) the amount of furnace maintenance required is considerably reduced by the absence of radiant tubes and by the use of scale-resistant inner covers.

The direct-fired furnace may be equipped with various types of burner. Figure 17 shows a furnace fitted with one type of luminous flame burner, designed for eight stacks of coils. Burners are arranged along both side-walls, with one burner at each end. Fuel gas and air are admitted into a combustion space behind a refractory tile in the furnace so as to produce a long luminous flame up the side-walls of the furnace. The products of combustion are vented through the three heat-resisting steel tubes suspended from the roof. These tubes are spaced between the coil stacks and extend downwards to within a short distance of the furnace base. At the upper end of each tube, outside the furnace, is an ejector actuated by compressed air to draw the products of combustion out of the furnace. The ejector system is interlocked with the valves controlling the furnace temperature so that under all conditions of firing the furnace pressure remains constant. This type of furnace has been described by Fisher.[7] Another method of direct-firing is described in Part II of the paper.

Inner Covers

The standard inner cover consists of a light steel cylindrical shell enclosed at one end. In a modification of the standard inner cover, with corrugated side-walls, it is claimed that faster heating and cooling rates can be obtained. A double-walled inner cover, sometimes used in conjunction with the edge heating method described later, consists of a standard inner cover to the inside of which is secured an open-ended cylinder having a slightly smaller diameter than the inner cover. This is shown in Fig. 16.

Inner covers were for a long time made of untreated mild steel. A well-designed mild-steel inner cover of, say, 54 in. dia., would have $\frac{1}{4}$-in. side-walls and a $\frac{5}{16}$-in. dished top. Alloy-steel lifting lugs would be fitted a short distance below the top of the cover. Side-walls of $\frac{3}{16}$ in. have been used, but give little more than half the life of $\frac{1}{4}$-in. side-walls. For inner covers of larger diameter, $\frac{5}{16}$-in. side-walls may be preferred.

The life of untreated mild-steel inner covers is unsatisfactory, especially with direct firing, and protective coatings for mild steel have therefore been investigated.[7] Aluminized mild-steel inner covers have given more than double the life of untreated mild-steel covers, and their scale-resistant properties warranted direct firing. With direct firing, aluminized mild-steel covers with $\frac{1}{4}$-in. side-walls may have a life of 250 heats, and of 150 heats with $\frac{3}{16}$-in. side-walls.

The aluminized mild-steel inner covers are not entirely satisfactory as they are liable to distort and they require a substantial amount of maintenance. For these reasons the tendency is to use heat-resisting alloy-steel inner covers rather than aluminized mild steel.

Inner covers are made of 18/8 or 25/12 chromium–nickel heat-resisting steel. The costs of these inner covers may be about $1\frac{1}{2}$ times and twice, respectively, the cost of aluminized mild-steel inner covers. Experience with heat-resisting steel inner covers indicates that the increased life and the reduced maintenance, compared with aluminized mild steel, more than outweigh the greater initial cost. Heat-resisting steel inner covers of, say, 54 in. dia., are made with $\frac{1}{8}$-in. side-walls and $\frac{3}{16}$-in. dished tops with reinforcing ribs.

It is sometimes necessary to increase the rate of cooling to keep the furnace in continuous operation. This is a matter of dissipating the heat from the charge through the inner cover to the atmosphere. Cooling may be expedited by blowing air against the inner cover, or by sprinkling water over it ; the water-cooling method should not be used until the cover has already cooled to a relatively low temperature, say, 350° C., as otherwise the life of the cover will be reduced.

Forced Circulation

It has long been the practice to install a fan to circulate the gas within the inner cover, thus promoting uniform temperature conditions from top to bottom of the stack of coils. Small coils, 30 in. dia. and less, can be conveniently heated in a circular furnace with a single inner cover accommodating several stacks of coils, and with a fan, driven by a motor of about 3 h.p., installed in the pedestal. The pedestal is designed so that the fan draws the gases downwards both through the centres of the coil stacks and between the stacks, the circulating gases returning up the side-walls of the inner cover. Furnaces of this type have been designed with loading diameters of

60 in. and 84 in. For larger coils, when the inner cover envelopes one stack of coils only, the fan draws the gases down the centre of the coil stack and returns them up the side-walls of the inner cover. In the case of the larger coils, circulating fans, even of low power, increased the furnace output. Various tests involving the use of greater fan power demonstrated the potentiality of forced circulation and led to the development of the edge heating method.

The normal method of transferring heat to the coil is mainly by radiation from the inner cover to the outer wrap of the coil and inwards radially to the inner diameter of the coil by conduction across successive wraps. Heat transmitted in this way has to traverse, between wraps, successive gaps of gaseous atmosphere which offer considerable resistance to heat flow. The thermal conductivity for heat flow in this direction is about 1·7 B.Th.U./sq. ft./hr.–°F./ft. On the other hand, heat transmitted to the coil edges can flow along the wrap parallel to the coil axis without such resistance. The thermal conductivity in this case is about 6·0 B.Th.U./sq. ft./hr.–°F./ft. Comparison of these two thermal conductivities will demonstrate the theoretical advantage to be obtained from heating a coil by transmission of heat to the coil edges.

In practice, the normal method of heating coils has been modified to the edge heating method by embodying the principle of transferring heat to the coil edges ; a furnace employing this principle is termed a convector furnace. One type of convector furnace is shown diagrammatically in Fig. 16. The essential features are the double-walled inner cover, the convectors between the coils, the cover plate at the top of the coil stack, and the high-velocity circulating fan in the pedestal, driven by, say, a 15-h.p. motor. The circulation path of the gas is indicated in Fig. 16. The circulating gas is discharged from the fan round the periphery of the pedestal and passes at high velocity up the annular space of the double-walled inner cover. The gas, after leaving the top of the annular space, is drawn through the convectors at high velocity to the centre of the coil stack and downwards to the fan. During the heating cycle, heat is transferred to the gas as it passes up the annular space and heat is delivered by the gas as it passes through the convectors, thus transferring heat to the coil edges. At the same time, heat is transferred by radiation from the inner cover to the outer wrap of the coil. During the cooling cycle, the circulation path of the gas remains as before, but in this case the gas receives heat as it passes through the convectors and it delivers heat to the inner cover as it passes up the annular space. This method not only increases the rate of heat transfer to the charge, but also, when the furnace is removed, the rate of dissipation of heat from the charge to the inner cover and thus to the atmosphere.

The effect on furnace output of increasing the fan power is indicated by the following figures for a multi-stack furnace annealing 15,000-lb. tinplate coils of 52 in. outside dia. and 20 in. inside dia. :

Horse-Power of Circulating Fan	Output per Foot of Stacking Height lb./hr.
1	106
5	140
15*	270

* Fitted with convectors ; maximum temperature spread in charge, 20° C.

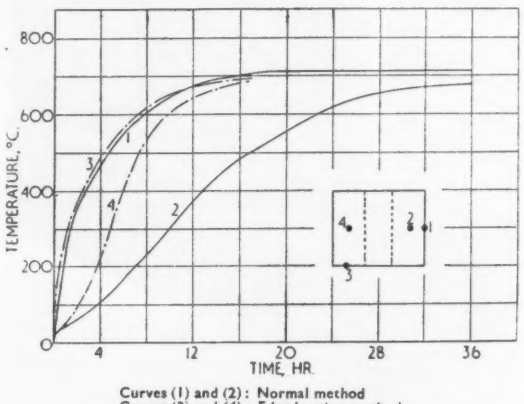
The following figures apply to single-stack furnaces designed to heat coils of narrow strip 42 in. outside dia. and 16 in. inside dia. :

Horse-Power of Circulating Fan	Output per Foot of Stacking Height lb./hr.
3	130
15*	210

* Fitted with convectors ; temperature spread in charge, 28° C.

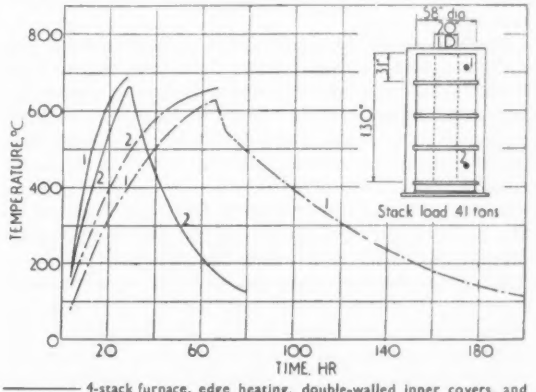
The foregoing figures demonstrate the advantage to be obtained from the edge heating method. The effects of coil size will also be apparent.

Armstrong and Schlitt[8] have compared furnaces employing the normal and the edge heating methods. This comparison is illustrated in Fig. 18, which gives actual heating curves for a charge of four 58-in. outside dia. tinplate coils weighing 37 tons. With the normal method the temperature spread after 32 hr. was 40° C., and 12° C. after 16½ hr. with the edge heating method. Both cycles produced satisfactory physical characteristics.



Curves (1) and (2) : Normal method
Curves (3) and (4) : Edge heating method

Fig. 18—Comparison of heating cycles for tinplate coils with and without edge heating



——— 4-stack furnace, edge heating, double-walled inner covers, and 20-h.p. circulating-fan motors

— — — 8-stack furnace, standard inner cover, and 3-h.p. circulating-fan motors

Fig. 19—Complete annealing cycles for tinplate coils with and without edge heating

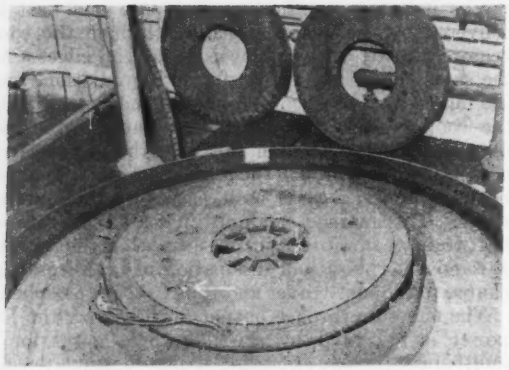


Fig. 20—Furnace base of single-stack convector furnace, showing convectors and pedestal thermocouple (indicated by arrow)

Figure 19 gives the time/temperature curves for two complete annealing cycles for tinplate coils treated in multi-stack furnaces. In both cases each coil stack comprised four 58-in. dia. coils having a total weight of 41 tons. In one case the furnace was fitted with 3-h.p. circulating fans and a standard inner cover, and in the other, the edge heating method, using 20-h.p. circulating fans, was employed.

For economic reasons the edge heating method is imperative for large coils, but little benefit is obtained from this method for small coils. Coils of 40 in. outside dia. and 16 in. inside dia. may be regarded as the smallest which can usefully be treated in the convector furnace. Smaller coils must be double-wrapped to form larger coils for the annealing process.

Convector furnaces have been designed with loading diameters of 42 in. to 78 in. Generally, the stacking heights are 80 in. to 150 in., which is greater than the stacking heights (about 80 in.) normally used for earlier portable furnaces.

The double-walled inner cover sometimes gives trouble due to distortion, and the tendency is now to use the standard inner cover as experience indicates that this may be used in place of the double-walled inner cover without loss of furnace output.

Convectors

The convector, or separator, is placed between the coils, providing a path for the circulating gas to flow towards the coil centre. Various designs of convector are used. One type, the compensating convector, is designed to increase the velocity of the circulating gas as it flows towards the coil centre and at the same time to provide an increased area for convective heat transfer, thus compensating for the heat radiated to the outer wrap of the coil and for the temperature change of the gas as it passes through the convector. The compensating convector is built up of a large number of curved vanes sandwiched between two annular discs, as shown in Fig. 20. Initially it was fabricated in mild steel, using $1 \times \frac{1}{8}$-in. flats for the curved vanes, and $\frac{3}{16}$-in. sheet for the annular discs, but this design is liable to distort and has not proved to be entirely satisfactory. In the latest design fewer vanes are used and are formed of $1 \times \frac{1}{2}$-in. flats. Another type of convector has straight vanes set at an angle to the radius, while a further type dispenses with the annular discs so that the vanes, and the circulating gas, are in direct contact with the coil edges. The last type is fabricated in 18/8 chromium–nickel heat-resisting steel.

Figure 21 shows a stack of coils with convectors in position. Normally, one convector is placed on the pedestal at the base of the coil stack and others at intervals up the stack. With narrow-strip coils, as many as six convectors may be used.

Temperature Control

For temperature control, one thermocouple is normally fitted in the side-wall of the furnace, and a spring-loaded sheathed thermocouple, which may be used for automatic control, is installed in the pedestal so as to press against the base of the coil stack (*see* Fig. 20). If the coil diameter for successive charges varies considerably, the pedestal thermocouple may not be satisfactory for control purposes ; it is then advisable to insert a thermocouple between two coils near the base of the stack and at the mean coil radius from the centre. With a convector furnace with a double-walled inner cover (Fig. 16), a thermocouple should also be inserted in the outer wraps of the top coil, since this is the hottest part of the charge. This thermocouple would then be used as the control couple. Figure 21 shows a coil stack fitted with these two thermocouples.

SELECTION OF FURNACES

Many practical and economic factors must be considered before selecting the type of furnace to be

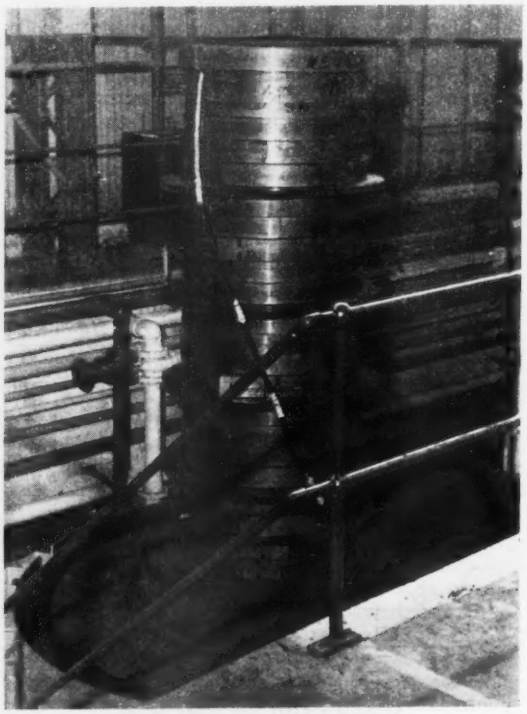


Fig. 21—Coil stack in convector furnace

Table I

TYPICAL OUTPUTS AND FUEL CONSUMPTIONS FOR COIL-ANNEALING FURNACES

Furnace Details	Method of Heating	Material Annealed	Designed Capacity					Average Fuel Consumption per Ton	
			Coil Dia., in.		Stacking Height, in.	Furnace Output, tons/week	Output, tons/week/ 100 sq. ft. of Floor Area	Power to Circulating Fans, kWh.	Fuel Input to Furnace
			Outside	Inside					
									kWh.
Pot Furnaces :									
With recuperator	Electric resistance	Narrow strip	42	28	48	60	12·5	..	190
With recuperator	Electric resistance	Tinplate	52	20	66	65	15·0	..	140
									Therms
Portable-Cover Furnaces:									
Single-stack, 15-h.p. circ. fan, with convectors	Radiant tube	Narrow strip	42	16	96	120	18·6	17	15·0
Single-cover, 84-in. loading dia., 3-h.p. circ. fan	Direct firing	Narrow strip	30	15	72	170	19·6	1·5	17·5
8-stack, 1-h.p. circ. fan	Radiant tube	Tinplate	52	20	96	440	22·6	1·7	12·3
8-stack, 1-h.p. circ. fan	Direct firing	Tinplate	52	20	96	510	26·2	1·6	9·4
8-stack, 15-h.p. circ. fan, with convectors	Direct firing	Tinplate	54	20	132	1800	100·0	8	9·0
4-stack, 15-h.p. circ. fan, with convectors	Direct firing	Sheet	72	24	144	1090	57·8	8	10·0

used. In many cases, the fuel to be used will be determined by local conditions, but clean gas or electricity are to be preferred. Pot furnaces may be fired by gas, but normally electric resistance heating is employed. Portable-cover furnaces, so far as furnace operation is concerned, can be heated equally well by gas or electric resistance elements, but economic considerations will normally indicate gas.

Fuel consumption is influenced by various factors, such as the annealing cycle and furnace utilization. The fuel consumptions given in Table I should be considered in the light of these qualifications.

Modern practice does not favour a portable-cover furnace with a designed capacity of less than about 100 tons/week. If a smaller throughput is contemplated, a pot furnace would be preferred. For large throughputs, however, the portable-cover furnace should be selected, for the following reasons :

(1) For a given throughput, the portable-cover furnace will have a lower capital cost than the pot furnace. The ratio of the capital costs of the portable furnace and the pot furnace is 1 : 2 for small outputs, and even more in favour of the portable furnace for larger outputs. This aspect is likely to be more important than all other considerations, making it imperative to select the portable-cover furnace in preference to the pot furnace.

(2) For a given throughput the portable furnace will require a smaller floor area than the pot furnace. The outputs of various types of furnace are given in Table I.

(3) Material handling is less for the portable furnace than for the pot furnace.

A possible disadvantage of the portable furnace is that it requires a crane of greater capacity and headroom than a pot furnace. A pot furnace of 4½ tons' capacity for 42-in. outside dia. coils requires a crane lift of about 8 ft., the total load being about 5 tons. A single-stack convector furnace designed for similar coils might have a capacity of 11 tons and a stacking height of 9 ft., and the furnace would require 26 ft. headroom. The portable furnace may sometimes be installed in a pit, as illustrated in Fig. 21. The weight of the single-stack portable furnace would be about 6 tons, although multi-stack furnaces may weigh as much as 50 tons.

To summarize, for throughputs of less than about 100 tons/week, pot furnaces heated by electricity are to be preferred. For larger throughputs the portable-cover furnace will generally be more economical. A modern portable-cover furnace will embody certain features such as direct-firing, heat-resisting steel inner covers, and, if coils of 40 in. dia. or more are to be treated, the edge heating method will be of advantage.

FUTURE DEVELOPMENTS

Rapid progress has recently been made in the development of the portable-cover furnace, and additional improvements can be expected as a result of further experience.

There may, in the future, be a transition from the batch process to the continuous strip annealing process. This process, which has real possibilities, has already been used with some success, but before it can have a more general application, there are certain inherent disadvantages to be remedied.

Acknowledgments

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The Söderberg Electrode System

By Herman Christiansen, jun., and B. Ydstie

SYNOPSIS

The World capacity of furnaces employing the Söderberg electrode system has increased rapidly during the last twenty years. The Söderberg electrode is continuous and self-baking, and its application in smelting furnaces, steel furnaces, and aluminium furnaces, is described. The method of manufacture of the electrode paste is outlined, and it is pointed out that the purest materials are required for electrodes for use in steel and aluminium furnaces.

In smelting furnaces, the Söderberg electrode system has given good service, and has a number of important advantages over other types of electrode. Extensive tests are being carried out to perfect the performance of the electrodes in steel furnaces. A new type of electrode system, employing vertical contact stubs, has simplified the operation of aluminium furnaces, and has made possible a high degree of mechanization. Furnaces using this system are completely closed. Fluorine and SO_2 are removed from the furnace gases and their adverse effects are entirely eliminated.

THE Söderberg electrode system has been applied to smelting furnaces since 1919 and to aluminium furnaces since 1923. Its success is clearly illustrated by the capacities of both types of furnace throughout the World, as shown in Figs. 1 and 2.

The Söderberg electrode is a continuous, self-baking electrode. It is prepared from green electrode paste, baked by waste heat from the furnace, and is renewed without interrupting the furnace operation. Once operation has commenced, the electrode will work continuously during the whole life of the furnace.

THE MANUFACTURE OF SÖDERBERG ELECTRODE PASTE

The electrode paste is prepared by mixing carbonaceous material of a certain granular composition with a tar pitch binder. Anthracite and metallurgical coke serve as dry components of paste for smelting purposes, the anthracite being calcined to remove volatile matter and to increase the electrical conductivity.

In the electrolysis of fused electrolytes, such as in the electrolysis of aluminium, the specifications as to the purity of the product are stricter than in the smelting practice. It is thus essential to use materials with the lowest possible ash content, such as petrol coke, pitch coke, and low-ash coke prepared from bituminous coal by a special treatment. These materials must also be subjected to calcination for removal of volatiles.

Dry matter and binder are next mixed in a mixing machine at 150–180° C., and cast into blocks of approximately 60 lb. each. These blocks are then ready for use in Söderberg electrodes. If the paste plant is close to the metallurgical plant, hot, plastic paste may be taken direct from the mixing machine to the electrodes, thus avoiding the reheating of the cold blocks before use, which is otherwise common practice.

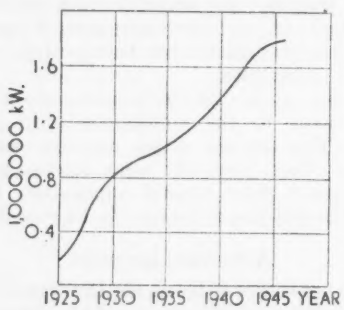

Fig. 1—World capacity of smelting furnaces with Söderberg electrode system

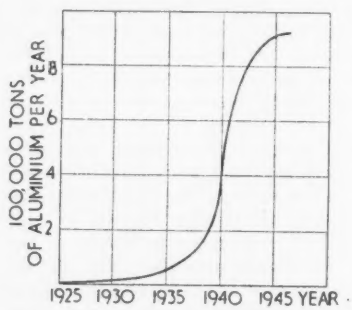

Fig. 2—World capacity of aluminium furnaces with Söderberg electrode system

THE SÖDERBERG ELECTRODE SYSTEM IN SMELTING FURNACES

Figure 3 shows a section through the Söderberg electrode system in a smelting furnace. The electrode proper is supported by a holder which embodies contact clamps, pressure ring, suspension mantle, and 'Wisdom' brakes. The holder is suspended from an automatically controlled hoist.

The electrode proper is formed by open-ended sections (6 to 7 ft. in length) of cylindrical (or rectangular), internally ribbed steel casings (B.W.G. 16–22), which are welded on top of each other and filled with Söderberg electrode paste. The casings are manufactured in the local workshop, only ordinary equipment, such as is used in sheet metal working practice, being required. The electrode is operated as follows: As the lower end is consumed in the process, the electrode is periodically lowered through the clamps. This 'slipping' is controlled by the 'Wisdom' brake, and is carried out under full load with complete safety. When the top end of the electrode (after a certain number of 'slippings') is

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Mr. Christiansen and Mr. Ydstie are at Elektrokemisk A/S, Oslo, Norway.

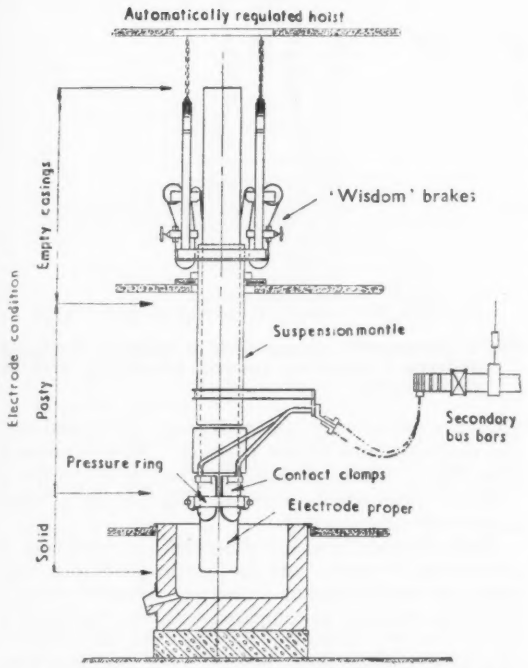


Fig. 3—Section through a Söderberg electrode system in a smelting furnace

level with the ' Wisdom ' gear, it is filled with electrode paste and a new casing section is mounted.

As indicated in Fig. 3, the lower end of the electrode is baked by the furnace heat and the heat evolved by the passage of current from the clamps. The upper part of the electrode remains in a pasty condition. This method of baking is characteristic of the Söderberg electrode and is fundamentally different from that of ordinary pre-baked electrodes. However, the properties of the resulting electrode are equal in every respect to those of the pre-baked carbons.

As will be seen from Table I, Söderberg electrodes have been built of various shapes and are used for many different products. The dimensions of the circular electrodes in use exceed by far the maximum size of pre-baked electrodes available.

Circular pre-baked electrodes, which may be nippled together so as to form a continuous electrode, are today manufactured in sizes up to only 40 in. If pre-baked electrodes of larger cross-section are required, a number of square or rectangular electrode sections must be combined into a ' bundle.' With these electrode ' bundles ' the generally favoured triangular arrangement of electrodes in a three-phase furnace cannot be achieved. Furthermore, ' bundles ' must be removed from the furnace for replacement each time they are worn down to the holder. This involves interruption of furnace operation and the discarding of butts.

The electrical conductivity of the Söderberg electrode is raised by the steel casing and the internal ribs. For this reason, it may be operated with a higher current density than ordinary carbon electrodes.

The Söderberg electrode has given very satisfactory service in the large number of installations where it is used. The equipment is sturdy and reliable, and breakages are rare occurrences. Electrode consumption varies to a considerable extent for the different products, even with furnaces of the same design and size ; it is mainly dependent on raw-material quality and furnace handling. For this reason, the presentation of a long list of figures would serve no useful purpose, and it should suffice to point out that the consumption of Söderberg electrodes is generally the same as that of pre-baked electrodes.

However, the Söderberg electrode leaves no butts, which must be discarded, and is thus more economical than discontinuous pre-baked electrodes. Furthermore, it is naturally superior in cases where the electrode is subject to excessive surface wear, on account of its protective iron casing.

THE SÖDERBERG ELECTRODE SYSTEM IN STEEL FURNACES

The Söderberg electrode has been used for many years in steel furnaces, in competition with amorphous carbon and graphite electrodes. The principle is the same as in smelting furnaces, except that the electrode is removed from the furnace for lengthening. In steel furnaces, the electrodes are exposed to much greater strain than in smelting furnaces, and experience has shown that fully satisfactory operational

Table I

DATA ON SÖDERBERG ELECTRODES INSTALLED IN SMELTING FURNACES

Product	Largest Furnace Capacity, kVA.	No. of Electrodes per Furnace	Shape of Electrodes*	Largest Electrode Dimensions	
				mm.	in
Pig iron†	12,000	3	C	1050	41½
Calcium carbide	40,000	1–3	C and R	2500	98
				280 × 65	110 × 25½
Ferro-silicon	10,200	1–3	C and R	2500	98
Ferro-manganese	12,000	1–3	C and R	2500	98
Ferro-chrome (H.C.)	10,900	3	C and R	850	33½
Copper and nickel matte	12,000	3–6	C	1400	55
Alumina	8,700	3	C	1000	39½
Phosphorus	11,250	3	C	1400	55

* C = circular, R = rectangular
† 18,000–20,000-kW. electric pig-iron furnaces, equipped with 1500-mm. (59-in.) dia. electrodes, to be erected shortly

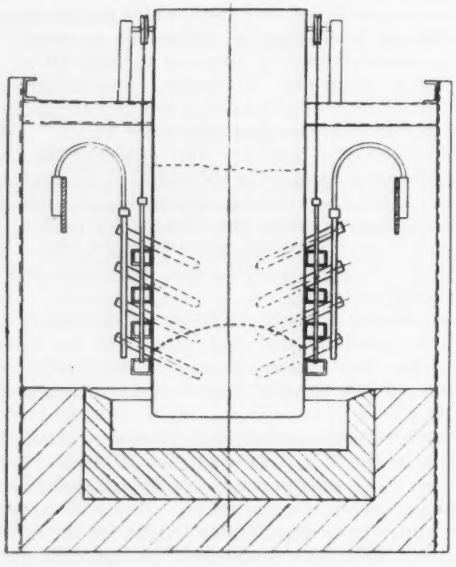


Fig. 4—Schematic arrangement of Söderberg electrode system in an aluminium furnace

results can be obtained only when using first-class electrode paste.

Extensive tests are now being carried out in Norway in order to perfect the performance of Söderberg electrodes in steel furnaces. There is reason to believe that these tests will result in an improved electrode design, even better suited to meet the exacting requirements of the modern steel furnace than is the case today.

THE SÖDERBERG ELECTRODE SYSTEM IN ALUMINIUM FURNACES

The Söderberg electrode is the only continuous electrode in commercial use in aluminium furnaces. It has been adopted by the aluminium industry all over the World. The type generally in use today was developed during the years 1932–34, and is shown schematically in Fig. 4. It is furnished with an aluminium casing enclosed by steel frames which give shape to the plastic paste before baking. The current is carried to the electrode by means of contact stubs laterally introduced into the plastic paste above the baking zone. The contact stubs remain embedded in the electrode throughout its downward movement and are extracted at a point just above the electrolyte. The electrode is also suspended by these contact stubs, and the regulation is effected by means of jacks ; it permits the closing of the furnace so that the gases may be sucked off and cleaned, and is installed in furnaces of up to 50,000 amp.

During the last few years a new system has been developed whereby the current is introduced, and the electrode is suspended, by means of vertical contact stubs, as shown in Fig. 5. An aluminium casing is no longer required, and the electrode is shaped and baked in a permanent steel casing. As the electrode is gradually consumed by the electrolysis it slides through the casing. The vertical contact

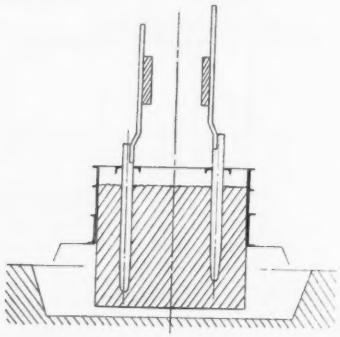


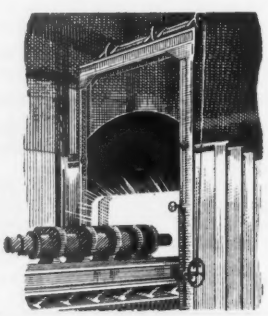
Fig. 5—Schematic arrangement of recently developed Söderberg electrode system, employing vertical contact stubs

stubs are periodically removed, reset, and baked into the electrode in a higher position. As will be seen from Fig. 5, the lower part of the casing is equipped with an apron which, together with the crust, forms a gas-collecting channel.

This electrode type has simplified the operation of aluminium furnaces, and has made possible a high degree of mechanization. The gas volumes are considerably reduced, as compared with the type having lateral contact stubs, and the gases may be collected in a concentrated form, permitting a complete combustion of tar vapours, CO, etc.

Compared with furnaces with pre-baked multiple anodes, the Söderberg electrode system shows reduced electrode costs, higher purity of metal, and improved conditions for the furnace operators. In contrast to furnaces with multiple anodes, furnaces equipped with Söderberg electrodes can be completely closed. The Söderberg system is thus the only system that allows the removal of fluorine and SO_2 from the furnace gases, and their detrimental influence is thus entirely eliminated. The importance of this for aluminium plants that are located in inhabited areas cannot be over-emphasized.

The latest development in the Söderberg electrode design has already been incorporated in experimental furnaces of 100,000 amp. The way is thus open for the construction of commercial installations with substantially larger unit capacity than is at present employed.



N E W S

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Special Summer Meeting in Norway, 1949

As announced in previous issues of the *Journal*, the 1949 Special Summer Meeting of the Institute is to be held in Norway, at the invitation of the Norwegian Metallurgical Society (Norsk Metallurgisk Selskap), and representatives of the Norwegian Metallurgical Industries. The meeting will take place from Saturday, 28th May to Tuesday, 7th June, 1949.

The M/S *Venus*, a fast, comfortable ship, of 7000 tons, has been made available for the meeting by the Bergen Steamship Co., Ltd. In addition to providing transport, the ship will act as the hotel for Members throughout the meeting.

Provisional details of the meeting have been given in earlier issues of the *Journal* (*viz.*, August and September, 1948; February, 1949 issues), but for the convenience of Members an abridged programme is given below:

Programme

The M/S *Venus* will leave Tyne Commission Quay, Newcastle-on-Tyne, at 8.0 P.M. on Saturday, 28th May, 1949. Arrangements will be made for dinner on board.

The whole of Sunday, 29th May, will be spent crossing the North Sea. Films will be shown during the day.

M/S *Venus* will arrive in Oslo at 6.0 A.M. on Monday, 30th May.

Monday, 30th May, 1949

The morning will be free in Oslo, with a reception and buffet lunch at Akershus Slott, given by the Lord Mayor and City Council of Oslo.

After lunch there will be visits to:

A/S Akers Mekaniske Verksted, Oslo (Shipbuilding yard)

A/S Christiania Spigerverk, Oslo (Steelmaking, rolling, wire-drawing)

A/S Kvaerner Brug, Oslo (Water turbine builders)

A/S Soennichsen Roervalseverket, Oslo (Manufacture of steel tubes by electric welding)

Emal jeverket A/S, Oslo (Deep drawing of mild and stainless steel).

There will also be sightseeing in Oslo—National Gallery, Frognerpark, with tea at Ekeberg, in which the ladies may join.

In the evening there will be a Banquet and Dance at the Hotel Bristol.

Tuesday, 31st May

There will be a joint meeting with the Norwegian Metallurgical Society, in the Aula of Oslo University. Dr. J. Görrissen, President of the Norwegian Metallurgical Society, will be in the Chair, and will make an opening speech of welcome.

The following papers will be presented and discussed:

"*Some Notes on Brittleness in Mild Steel*," by J. Görrissen

"*Experiences in the Study of Isothermal Transformations*," by T. F. Russell and C. Mavrocordatos

"*The Acceleration of the Rate of Isothermal Transformation of Austenite*," by M. D. Jepson and F. C. Thompson

"*Determination of an Isothermal Transformation Diagram with an Optical Dilatometer*," by J. K. L. Andersen

"*The Properties of Olivine and its Use for Refractories and Moulding Sands*," by K. J. Stenvik.

There will be visits to various works in the afternoon, and sightseeing in Oslo, in which the ladies may join—Folkemuseet, and Viking ships, ending at Dronningen, where lunch will be provided; afterwards there will be a sightseeing bus drive in and around Oslo, with tea at Holmenkollen Sanatorium.

Wednesday, 1st June

M/S *Venus* will arrive at Kristiansand at 10.0 A.M. There will be visits to:

A/S Falconbridge Nikkelverk (Electrolytic refining of nickel and copper)

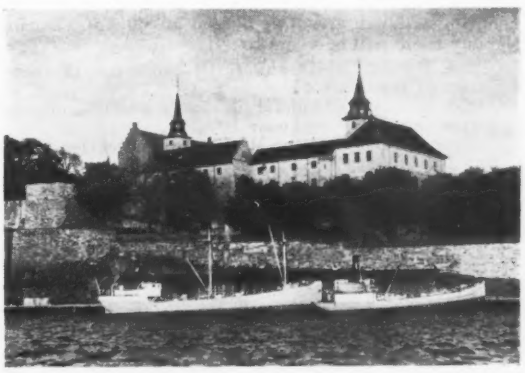
A/S Fiskaa Verk (Manufacture of ferro-alloys and Söderberg electrode paste).

Lunch will be taken on board, and in the afternoon there will be an excursion by motor boat in the fjord near Kristiansand, with picnic tea.

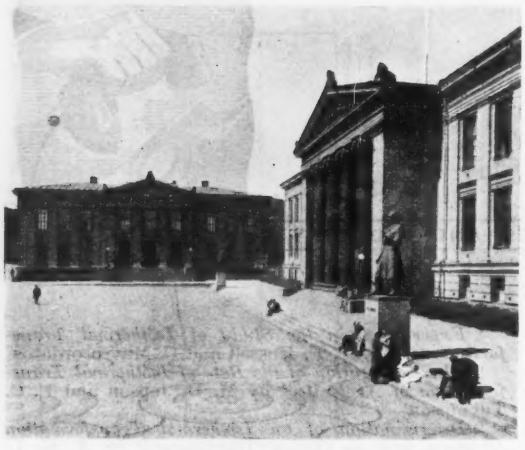
In the evening M/S *Venus* will leave Kristiansand. There will be technical discussion on board, Sir Andrew McCance in the Chair. The following papers will be presented and discussed:

"*The Manufacture of Electric Steel in Great Britain*," by the Electric Process Sub-Committee of the Steel Making Division of the British Iron and Steel Research Association

"*The Söderberg Electrode System*," by H. Christiansen, jun., and B. Ydstie (the paper will be illustrated by slides)



Akershus Slott



Aula of Oslo University

"*The Electrochemical and Electrometallurgical Industry of Norway*," by C. W. Eger

"*A Brief History of Electric Pig-Iron Smelting in Norway*," by H. Christiansen, jun.

"*Features from the Planning of an Electric Smelting Plant for Pig Iron in Mo i Rana*," by B. Muller

"*The Determination of Red Shortness in Mild Steel*," by J. Görrissen

A special English number of the Norwegian *Journal of Chemistry, Mining, and Metallurgy*, is being produced for the meeting, and will be available on board. The papers by Dr. J. Görrissen and Mr. B. Muller will be published in the Norwegian journal.

Thursday, 2nd June

M/S *Venus* will arrive at Ålvik in Hardângerfjord at 9.0 A.M. There will be a visit to A/S Bjoelvefossen (Electric manufacture of ferro-alloys). After which, M/S *Venus* will proceed to Odda/Tyssedal, where there will be visits to :

A/S Det Norske Zinkkompani (Electrolytic refining of zinc)

Odda Smelteverk A/S (Electric manufacture of calcium carbide and cyanamide)

A/S Tyssefaldene Power Station, and the lake Ringedalsdammen.

In the afternoon there will be a motor-bus excursion to Laatefoss Waterfall, and Seljestad, in which the ladies may join. The evening will be spent on board, proceeding to Bergen.

Friday, 3rd June

M/S *Venus* will arrive in Bergen at 8.0 A.M. During the day there will be visits to :

A/S Bergens Bliktrykkeri (Manufacture of metal cans and containers)

A/S Horsöy Sildoljefabrik (Large herring-oil and herring-meal factory, near Bergen

Sverre Munck Electro-Mechanical Industries (Crane and lift builders)

Alvöens Papirfabrik A/S (Paper factory).

There will also be a sightseeing motor-bus excursion in and near Bergen, in which the ladies may join. Lunch will be taken on board. In the evening there will be a Dinner and Dance at Hotel Flöyen, Bergen.

Saturday, 4th June

M/S *Venus* will arrive at Årdal at 10.0 A.M., where there will be visits to :

Heirsnosi Viewpoint, in which the ladies may join

A/S Årdal Verk Aluminium Plant

Upper Årdal Power Station, in which the ladies may join

A/S Årdal Verk Electric Pig-Iron Plant.

There will be a Dinner-Dance on board in the evening.

Sunday, 5th June

M/S *Venus* will proceed to Balestrand. Lunch will be taken at Hotel Kvikne, Balholm.

Monday, 6th June

M/S *Venus* will arrive in Bergen at 2.0 A.M. Scandinavian members will disembark at 6.0 A.M., and the ship will proceed to the United Kingdom, arriving at Newcastle-on-Tyne at 7.0 A.M. on Tuesday, 7th June.

Reception Committees

The main Norwegian Reception Committee, under the Chairmanship of Mr. GUNNAR SCHJELDERUP, Managing Director of Christiania Spigerverk, has arranged a very attractive social programme, in which the ladies will take part.

With Mr. CHRISTIAN SOMMERFELT as Secretary, the other members of the main committee are as follows :

Mr. HARALD ARNESEN (High Court Advocate)
Mr. HERMAN CHRISTIANSEN (High Court Advocate)
Dr. JOHAN GÖRRISSEN (President, Norwegian Metallurgical Society)
Mr. ALF IHLEN (A/S Strömmens Verksted)
Mr. ALF MONRAD-AAS (A/S Elektrokemisk)
Mr. AAGE OWE (A/S Årdal Verk)
Mr. ULF STYREN (A/S Norsk Jernverk).

A Ladies' Committee, with Mrs. LAILA SCHJELDERUP as Chairman, has been appointed, and there will be local committees at Christiansand, Odda, Bergen, and Årdal.

Biographical notes of Mr. SCHJELDERUP and Dr. GÖRRISSEN appear in the frontispiece to this issue.

Mr. Christian Sommerfelt, Secretary to the Board and to the Managing Director of Christiania Spigerverk, Oslo, was born in Oslo in 1916, and finished his education as an economist at the University of Oslo, in 1939. After two years' activity in Norway, Mr. Sommerfelt spent three years in England during the war, partly in the Royal Norwegian Ministry of Reconstruction, Industries Department, and partly as a liaison officer with a British unit in Scotland. He also trained for Special Operations in the Norwegian Indepedent Company. After the war, he became office manager of the newly established Norwegian Industries Development Association. He has been a member of two official commissions dealing with postwar industrial problems, and of the Norwegian Delegation to the O.E.E.C. conferences in Paris. Mr. Sommerfelt took over his present position in 1946.

Norwegian Metallurgical Society

The Norwegian Metallurgical Society (Norsk Metallurgisk Selskap) was founded in Oslo in 1936 ; its first President was Mr. SIGURD WESTBERG, now a director of the Refined Stainless Steel Co., Ltd., Rotherham.

The Society handles its own administration, but is affiliated to the Polytechnic Association of Oslo.

The main purpose of the Society is to arrange technical meetings and discussions and to promote technical co-operation between Norwegian metallurgists.

A summer meeting is held regularly in different parts of the country in combination with a visit to local

metallurgical works. This is important, since it helps to establish contact between metallurgists from various parts of the country and to emphasize the national and not local character of the Society.

The Society takes part in the publishing of the journal *Tidsskrift for Kjemi, Bergvesen og Metallurgi* ("Journal of Chemistry, Mining and Metallurgy").

The Society has at present about 200 members, of which 30 are company members. Members of the Committee at present are:

Dr. Ing. JOHAN GÖRRISSEN, Director of Research, A/S Christiania Spigerverk (*Chairman*)
DAG NICKELSEN, Chief Engineer, A/S Norsk Aluminium Company
GUNNAR HÖRGAARD, Director, Larvik Smelteverk A/S
JACOB AALL DAHL, Departmental Manager, Myrens Verksted A/S
F. C. COLLIN, Director of Research, A/S Elektrokemisk (*Secretary*).

Awards

Bessemer Gold Medal for 1949

The Bessemer Gold Medal for 1949 has been awarded to Professor J. H. Andrew, of Sheffield University, in recognition of his distinguished services to metallurgy and the iron and steel industry, with special reference to the valuable research work which he has conducted, or which has been carried out under his guidance, and also in acknowledgment of his services to metallurgical education.

Professor Andrew, Professor of Metallurgy and Dean of the Faculty of Metallurgy, University of Sheffield, obtained a First Class Honours Degree in Chemistry at the University of Manchester, where he became a Research Fellow and Demonstrator, and was awarded the Carnegie Scholarship of The Iron and Steel Institute. Before going to Sheffield University, Professor Andrew was Chief of the Metallurgical Research Department, of Messrs. Armstrong Whitworth and Co., Ltd., Manchester.

Sir Robert Hadfield Medal for 1949

The Sir Robert Hadfield Medal for 1949 has been awarded to Mr. M. W. Thring, in recognition of his studies on the Theory of Heat Transfer in Open-Hearth Furnaces.

Mr. Thring has been Head of the Physics Department of the British Iron and Steel Research Association since July 1945. He took First Class Honours in Mathematics and Physics at Cambridge, and received the Rouse Ball Prize in 1937. He was previously Scientific Officer in charge of the Combustion Research Laboratory of the British Coal Utilization Research Association, and has published many papers on fuel utilization. Mr. Thring served on the Temperature Measurement Committee of the British Standards Institution, and took part in drafting the B.S. Specification No. 1041 on this subject.

Williams Prize for 1948

The Williams Prize (£100) for 1948 has been awarded to Mr. J. S. Bryan, for his paper with Mr. J. B. R. Brooke on, "Gaseous and Liquid Fuels in Iron and Steel Works." (*Journal of The Iron and Steel Institute*, 1948, vol. 158, January.)

Mr. Bryan served his apprenticeship with Messrs. John Lysaght, and returned to that firm as technical assistant to the blast-furnace manager after serving in the Royal Air Force from 1943 to 1946. From 1947 he was Fuel Engineer at Messrs. John Lysaght, Ltd., of Scunthorpe. In March 1949 he joined the Morgan Crucible Co., Ltd., of Battersea, S.W.11.

Ablett Prize for 1948

The Ablett Prize for 1948 has been awarded (£50 each) to Mr. G. S. Martin and Mr. M. Y. Harvey, for their paper on, "The Maintenance of Electrical Machinery in Iron and Steel Works." (*Journal of The Iron and Steel Institute*, 1948, vol. 158, April.)

Mr. G. S. Martin has been chief engineer at the Lanarkshire Steel Co., Ltd., since 1947. Previously, he held positions with Metropolitan-Vickers, Ltd., Manchester, the Glasgow Corporation Transport Department, the Clyde Valley Electrical Power Company; Messrs. Brown and Aitkin, London; and Messrs. Colvilles, Ltd., at their Dalzell Steel Works.

Mr. M. Y. Harvey has been works electrical engineer at the Glengarnock Works of Messrs. Colvilles, Ltd., since 1945. He was previously in the Drawing Office of Dalzell Works. He served his apprenticeship in electrical engineering with the Lanarkshire Steel Co., Ltd., Motherwell.

Andrew Carnegie Trust Funds

The Council have made grants from the fund to the following:

Mr. G. R. BISH (Port Talbot): £250 to assist him in a research on the effect of cold-working on the austenite–martensite reaction during isothermal transformation of steel.

Mr. P. L. CHANG (Sheffield): £250 to assist him in a research on hydrogen diffusion at elevated temperatures.

J. S. Bryan

M. W. Thring

G. S. Martin

M. Y. Harvey

Relations with Foreign Societies

Arrangements have been made for collaboration of the Institute with Associazione Italiana di Metallurgia, of Milan, as from 1st January, 1949. A reduced subscription to the Association will be payable by Members or Associates of the Institute.

New Austrian Metallurgical Society

Dr. C. H. DESCH, F.R.S., will deliver a lecture at the first General Meeting of the newly formed Austrian Metallurgical Society, which will take place during the Centenary Celebrations of the Leoben Mining and Metallurgical University, beginning 20th May, 1949, at Leoben.

The name suggested for the new Austrian Metallurgical Society is Osterreichische Hütte.

NEWS OF MEMBERS

▶ The Hon. R. A. BALFOUR, director of Messrs. Arthur Balfour and Co., Ltd., Messrs. C. Meadows and Co., Ltd., The Eagle and Globe Steel Co., Ltd., and Messrs. Tinsley Rolling Mills Co., Ltd., and who was Master Cutler two years ago, has been nominated as next president of the Sheffield Chamber of Commerce.

▶ Dr. R. W. BAILEY, of the Metropolitan-Vickers Electrical Co., Ltd., has been elected a Fellow of The Royal Society.

▶ Mr. P. BERGER has left the position of chief chemist and electroplating technician at Messrs. Wm. Bate and Sons, Ltd., of Walsall, Staffs., and has joined Messrs. Britachrome Co., Ltd., of Ladywood, Birmingham, 16.

▶ Mr. F. G. BIRD has left Messrs. Jarrow Metal Industries, Ltd., Jarrow.

▶ Mr. D. W. BROOKER is now employed on experimental brassplating work at the John Bull Rubber Co., Evington Valley Road, Leicester.

▶ Mr. J. CHIPMAN delivered the Howe Memorial Lecture at the annual meeting of the American Institute of Mining and Metallurgical Engineers, held on 14th February, 1949.

▶ Señor A. DE CHURRUCA has been awarded the Grand Cross of Isabel the Catholic; he has also been elected President of the Spanish Iron and Steel Institute.

▶ Mr. L. H. COPE has been appointed research metallurgist, in the department of research and technical development, at Messrs. Stewarts and Lloyds, Ltd., Corby, Northants.

▶ Mr. S. P. EFTHYMIADES has left Cyprus, and is now manager of the engineering and motor department of Messrs. A. G. Leventis and Co., Ltd., at Accra, Gold Coast.

▶ Mr. H. H. EGGINTON has left the Pyrene Company of Brentford, Middlesex, to become technical manager with the British Thermostat Co., Ltd., of Sunbury-on-Thames, Middlesex.

▶ Dr. U. R. EVANS has been elected a Fellow of The Royal Society.

▶ Mr. H. A. HALUPKA left England on the 3rd March, 1949, to take up the position of metallurgist with The South West Africa Co., Ltd., near Grootfontein, South West Africa.

▶ Mr. W. H. HIGGINBOTHAM, chairman of Messrs. Edgar Allen and Co., Ltd., has been nominated a Vice-President of the Sheffield Chamber of Commerce.

▶ Dr. V. J. D. HILL has resigned his position as technical-commercial manager of the industrial department of Messrs. Philips Electrical, Ltd., to become manager of the Electric Welding Division of Thermal Welding Products, of Benoni, South Africa.

▶ Mr. S. A. HISCOCK has left the Arc Manufacturing Co., Ltd., to join the British Non-Ferrous Metals Research Association, as research assistant.

▶ Mr. B. HOOPER has left Messrs. Hard Metal Tools, Ltd., Wolverhampton, and is now chief chemist and metallurgist of the Coventry Gauge and Tool Co.. Ltd., Coventry. He has been elected an Associate of the Institute of Metals.

▶ Mr. J. D. HULLOCK has been appointed foundry manager of Sheepbridge Stokes Centrifugal Castings Co., Ltd., at Chesterfield.

▶ Mr. Z. Z. J. KOSARSKI is foundry manager at The Sheepbridge Stokes Centrifugal Castings Co., Ltd., at Sutton-in-Ashfield, Notts.

▶ Mr. F. N. LLOYD, director of Messrs. Ibbotson Bros. and Co., Ltd., has been nominated a Vice-President of the Sheffield Chamber of Commerce.

▶ Mr. F. A. MARTIN, of Messrs. S. Osborn and Co., Ltd., has been appointed leader of the first British team visiting the United States to study production methods.

▶ Mr. R. P. MIDDLETON, late director of Messrs. F. H. Wheeler (Sheffield), Ltd., has been appointed manager of Messrs. Barr's (Sheffield), Ltd., of Broad Lane, Sheffield, and is also on the board of directors. This newly formed company is in association with Messrs. Electric House (Denton), Ltd.

▶ Mr. D. S. MURTY, assistant superintendent of the Development Detachment at Ambarnath Ordnance Factory, has been transferred to the Inspectorate of Metal and Steel, Ishapore, West Bengal.

▶ Señor A. PLANA has been elected Director of the Spanish Iron and Steel Institute.

▶ Mr. E. J. PODE, managing director of The Steel Co. of Wales, Ltd., has been appointed a member of the Oil Consumers' Council, recently set up by the Ministry of Fuel and Power.

▶ Mr. R. R. ROBERTS, metallurgist at Murex Welding Processes, Ltd., of Waltham Cross, Herts., has been awarded the degree of M.A. of Cambridge University.

▶ Professor E. OROWAN delivered the annual lecture to the Institute of Metals division of the American Institute of Mining and Metallurgical Engineers, at their annual meeting held on 14th February, 1949.

Layout of Integrated Works

A limited number of reprints of the paper by H. Mardon and J. S. Terrington, which appeared in the April issue of the *Journal*, are available for sale. Price 7*s*. 6*d*. (5*s*. to members). Price to libraries and booksellers 6*s*. 3*d*.

▶ Dr. G. V. SLOTTMAN has been appointed director of research and engineering of Air Reduction Co., Inc., N.Y.

▶ Mr. J. TAYLOR has been awarded the Riley Medal by the West of Scotland Iron and Steel Institute.

▶ Mr. H. G. THOMAS has left the Royal Ordnance Factory, Crewe, to take up the position of service engineer at Messrs. Davy and United Engineering Co., Ltd., Sheffield.

▶ Mr. P. TRUSCOTT, student at University College, Swansea, has taken an appointment with the New Chrome Metal Co., Ltd., of Cardiff.

▶ Mr. E. T. TÜRKDOĞAN has taken up an appointment with the Department of Metallurgy, Sheffield University.

▶ Mr. F. WALKER has joined the chemical research laboratory of Messrs. B.I.C. Cables Ltd., Kirkby Trading Estate, near Liverpool.

▶ Mr. G. R. WARD was appointed blast-furnace manager at the Cargo Fleet Iron Co., Ltd., Middlesbrough, Yorks., from 1st January, 1949.

▶ Mr. B. C. WOODFINE has been awarded the degree of

B.Met. (first-class honours) of Sheffield University, and is now engaged in post-graduate research.

▶ Sir CHARLES WRIGHT announced his resignation from Guest Keen Baldwins Iron and Steel Company and its subsidiaries at a board meeting held on 8th March, 1949. This was received with the greatest regret, and the chairman, Mr. J. H. Jolly, emphasized the debt which the company owed to Sir Charles for his past work.

Sir Charles joined the board on the formation of the company on 24th March, 1930, and became deputy chairman. He was chairman from 1st January, 1936, to 14th January, 1947, when he resigned his office as chairman but remained as director. Sir Charles was chairman of Baldwins, Limited at the time when the heavy steel interest of Baldwins, Limited was amalgamated with that of Guest Keen and Nettlefolds, Ltd. to form Guest Keen Baldwins Iron and Steel Co., Ltd.

He was also prime mover in the conception of building the East Moors Works at Cardiff, which was completed in 1936, and is one of the most modern in the country, producing approximately 575,000 ingot steel tons per annum.

Sir Charles was elected a life member of The Iron and Steel Institute in 1902. He was elected a Member of Council in 1915, Vice-President, 1924, President, 1931 to 1933, and Honorary Member of Council in 1943.

▶ Mr. J. WURTH, former director of Messrs. Société Anonyme, John Cockrill, at Athus, Belgium, has been made a director of metallurgy of the company's works at Seraing.

Corrections

▶ The Council regret that the announcement of the death of Mr. A. Smith, of West Bromwich, was inserted in error in the January issue of the *Journal*. The announcement does not refer to Mr. Arthur Smith, of 76 Beaconsfield Street, West Bromwich.

▶ Dr. S. T. JAZWINSKI—In the March issue of the *Journal*, p. 248, Dr. Jazwinski's name was incorrectly spelt Jazninski.

▶ Mr. CLEMENT HULME, assistant works manager of the Port Talbot and Margam works of The Steel Company of Wales, Ltd., was, in the April issue of the *Journal*, stated to have been formerly assistant blast-furnace manager at the North Works of that Company. This, of course, should have read, blast-furnace manager of the North Works of the Appleby-Frodingham Steel Company.

Obituary

Mr. D. R. P. WILLIAMS (Percy Williams), late of Messrs. Guest Keen Baldwins Iron and Steel Co., Ltd., Cardiff, on 12th December, 1948.

Mr. O. W. HAWKE, of Worksop, Notts., on 2nd February, 1949.

Mr. J. H. G. MONYPENNY, late of Messrs. Brown, Bayley's Steel Works, Ltd., on 2nd March, 1949.

Mr. WILLIAM FREDERICK ROWDEN, director of the Climax Molybdenum Company of Europe, Ltd., on 16th March, 1949.

CONTRIBUTORS TO THE JOURNAL

H. Christiansen, jun.—Metallurgist at Elektrokemisk A/S, Oslo. Mr. Christiansen was born in 1914. He graduated from Technische Hochschule, Dresden, in 1938, and has since held posts with the following companies: Rhodesia Chrome Mines, Ltd., Southern Rhodesia; Det Norske Nitrid A/S, Tyssedal, Norway; A/S Meraker Smelteverk, Kopperå, Norway; I.C.I. (General Chemicals), Runcorn, England.

H. Christiansen

C. W. Eger

After a period of military service, Mr. Christiansen took up his present position in 1945.

C. W. Eger was born in 1880, in Oslo. He graduated as a diploma engineer from the Technical High School in Dresden in 1906. From 1907 to 1908, he was manager of Eyde's Engineer Office. He took part in planning the dams supplying water power for the Norwegian nitrogen industry. From 1908 to 1910, he was in charge of the building of the Lienfos power plant. From 1910 to 1912, he was general manager of A/S Arendals Fossekompani, and in charge of the building of Böilefoss power plant. From 1912 to 1920 Mr. Eger was member of the board and a director of the Elektrokemisk A/S. During this period he took part in starting A/S Arendal Smelteverk, Det Norske Nitridaktieselskap, A/S Grong Gruber, A/S Björlvefossen, and other industrial undertakings. He was also member of the board of several other industrial companies. From 1945 he has been chairman of the committee for Christiania Bank og Kreditkasse, as well as vice-chairman of the board of Norden's Insurance Company. He is a member of a number of official commissions. During the war he was in charge of the Home Front's Employment Committee.

K. J. Stenvik—Manager of A/S Olivin, Åheim, Norway. Mr. Stenvik, author of the paper on olivine, has been a member of the Government Laboratory for Investigations of Raw Materials, Oslo, Norway, for about 25 years. He has been engaged in research on technical refractory materials and geochemical and spectrochemical analyses, especially concerning ores and minerals. During 1929 to 1932, he carried out similar investigations at Mineralogisches Institut, Göttingen, Germany. He took up his present position in 1946.

J. K. Johanssen, A.I.M.E.—Technical director at A/S Sydvaranger, the largest mining and exporting company

K. J. Stenvik

J. K. Johanssen

J. K. L. Andersen

W. Lund

H. Edwards

J. B. Davis

for iron ores in Norway. Mr. Johanssen obtained a mining engineer's degree at the Technical University of Norway in 1924, and subsequently held the following positions : In 1925, he was mining and milling engineer at Kvina Molybdenum Mine ; mine and mills superintendent at Röros Kobberverk from 1926 to 1928 ; laboratory engineer at The General Engineering Co., Salt Lake City, Utah, U.S.A., from 1928 to 1929 ; consulting ore-dressing engineer to Ferd. P. Egeberg, Oslo, from 1929 to 1938 ; mill superintendent at Aktiesèlskabet Sydvaranger, Kirkenes, from 1938 to 1940 ; manager of the mining department of O/Y Vuoksenniska A/B, Finland, from 1940 to 1946. Mr. Johanssen took up his present position in 1947.

J. K. L. Andersen, Met.Eng.—Assistant in the smelting department of A/S Stavanger Electro-Stallverk, was born in 1919, in Odda. After studying at the Norwegian Technical University, he became assistant to the manager at A/S Bremanger Kraftselskab, Svelgen, on the pig iron plant, from February 1943 to May 1945. He graduated from the Norwegian Technical University in the spring of 1948 in the mining division, specializing in metallurgy. Mr. Andersen is a member of N.I.F., and a junior member of A.I.M.E.

W. Lund, A.I.M.E.—Chief engineer at A/S Sydvaranger, and the Rana Iron Ore Co. Mr. Lund was born in 1909, and obtained a mining engineer's degree at the Technical University of Norway in 1932. From 1932 to 1935 he was mill superintendent assistant of the Stordö Pyrites Mine. From 1935 to 1937 he was mill superintendent of the Titania Mine. Mr. Lund took up his present position in 1937.

H. Edwards, F.R.I.C., F.I.M., A.M.I.Chem.E.—Manager of the cold strip mill at the Hawarden Bridge Steelworks, Shotton, of Messrs. John Summers and Sons, Ltd., was born near Brymbo in 1902. He was educated at the Hawarden Grammar School, and the Liverpool Technical College. He passed the Associate examination of the Royal Institute of Chemistry, and in 1938 he was elected a Fellow. Mr. Edwards started work in the chemical laboratories, and later studied process problems. In 1931, he was appointed manager of the galvanizing department and was responsible for many improvements in the process of sheet galvanizing, and for the operation of the Sendzimir galvanizing furnace. He is a member of the Rolling and Coatings Committees of the British Iron and Steel Research Association and Chairman of the Spent Pickle Liquor Sub-Committee. He is one of the founders of the Liverpool Metallurgical Society. Mr. Edwards took up his present position in 1940.

J. B. Davis, M.A., A.M.I.Mech.E.—Member of the engineering staff of the Research and Development Department of The United Steel Companies, Ltd. Mr. Davis was educated at Cranleigh School, and Magdalene College, Cambridge, where he obtained 1st Class Honours in the Mechanical Sciences Tripos in 1936. He then joined the Primitive Gas Company. After a period of training, including studies at the Dundee School of Economics, he worked for three years in Buenos Aires. He returned to England in 1941, and obtained a commission in the R.N.V.R. As a qualified radar officer, he served in the cruiser H.M.S. *Charybdis*, and in other appointments. Mr. Davis joined the staff of The United Steel Companies, Ltd., in 1946.

R. D. Pollard, A.Met., F.I.M.—Manager of the Research Department, Messrs. Samuel Fox and Co., Ltd. Mr. Pollard received his technical education at Sheffield University, being awarded the Associateship in Metallurgy in 1919. After five years' service in the general chemical laboratory of Messrs. Cammell Laird and Co., Ltd., he joined the research staff of Messrs. S. Fox and Co., Ltd., as chief assistant under the late Dr. Swinden. He was later appointed manager of the department, a position which he holds at the present time under Mr. G. R. Bolsover, technical director to the firm.

D. Jepson, M.Sc.—Physical metallurgist in the research department of Messrs. Hadfields, Ltd., Sheffield. Mr. Jepson was born in 1925 at Urmston, near Manchester. He was at Stretford Grammar School from 1935 to 1943, and proceeded to the Honours School of Metallurgy, Manchester University, whence he graduated with first class honours in 1945. He subsequently spent three years on post-graduate research at Manchester University, and was awarded the degree of M.Sc. in 1947. He took up his present position in January, 1949.

F. C. Thompson, M.Sc., D.Met., F.I.M. Professor of Metallurgy at the University of Manchester. Professor Thompson obtained the degree of B.Met. at the University of Sheffield in 1911, and later he obtained the degree of D.Met. He was on the staff at the University

R. D. Pollard

C. Mavrocordatos

of Sheffield from 1911 to 1920. He was awarded the Sorby Fellowship for 1920–1921.

B. Ydstie

T. F. Russell, A.Met., F.I.M.—Senior Metallurgist at the English Steel Corporation, Ltd. Mr. Russell studied under the late Dr. J. E. Stead, F.R.S., and obtained first class honours (Silver Medal) in Iron and Steel Manufacture at the City and Guilds examination. He was for two years chemist-in-charge at the Dunderland Iron Ore Co., Norway; three years chemist-in-charge at the Islip Iron Co., Ltd., Thrapstone; eleven years with Messrs. Steel, Peech and Tozer, of Rotherham, as chief assistant chemist, and later chief assistant in the research department, and for four and a half years Investigator for the British Non-Ferrous Metals Research Association, at Sheffield University. Mr. Russell was for two years evening lecturer at Rotherham Technical School in iron and steel manufacture and in fuel and refractories, and for eleven years evening demonstrator in metallurgy, including four years as lecturer in metallurgical physics, at Sheffield University.

Mr. Russell was awarded a Carnegie Research Scholarship in 1919. He is the author and joint author of many papers on original research, most of which have been published in the *Journal* of The Iron and Steel Institute. He took up his present position in 1929.

C. Mavrocordatos, B.Met.—Assistant Metallurgist, English Steel Corporation, Vickers Works, Sheffield. Mr. Mavrocordatos, after graduating from an Athens Public School, studied chemistry in the University at Athens. In 1938 he came to England to study metallurgy under Professor J. H. Andrew. In 1941, he interrupted his studies in the University and joined the Research Department of the English Steel Corporation, which he left in 1943 to serve in the Royal Hellenic Navy. At the end of the war Mr. Mavrocordatos returned to Sheffield University to complete his studies. In 1946 he was awarded the degree of B.Met. (1st Division), and rejoined the Research Department of the English Steel Corporation.

B. Ydstie—Metallurgist at Elektrokemisk A/S, Oslo. Mr. Ydstie was born 26th April, 1921. He graduated from Norges Tekniske Högskole, Trondheim, in 1947, and took up his present position in July, 1947.

IRON AND STEEL ENGINEERS GROUP

The **Tenth Meeting** of the Iron and Steel Engineers Group will be held at the offices of the Institute, 4 Grosvenor Gardens, London, S.W.1, on Wednesday, 22nd June, 1949.

Three papers will be presented and discussed as follows:

"*Annealing Plant for Mild-Steel Sheets and Coils*," by R. D. Pollard, H. Edwards, J. F. R. Jones, and J. B. Davis

"*Continuous Steel Strip Pickling*," by R. W. Treasure

"*The Disposal of Spent Acid Pickling Liquor*," by W. B. Wragge.

The first paper is published in this issue (*see* pages 79–97): the other papers will be published in the June issue of the *Journal*.

THE INSTITUTION OF METALLURGISTS

Examinations, 1949

The next examinations for Fellowship, Associateship, and Licentiateship, of The Institution of Metallurgists, will be held in September, 1949. Applications for entry, to be made on a form obtainable from the Registrar-Secretary, must be submitted before 1st June, 1949. Papers set at previous examinations are available at 1*s*. per set, from the Registrar-Secretary of The Institution, 4 Grosvenor Gardens, S.W.1.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Cupola and Converter Refractories

A Conference on cupola and converter refractories, arranged by the Steel Castings Division, is to be held at Ashorne Hill, Leamington Spa, on 12th and 13th May, 1949, with Dr. A. H. B. Cross in the Chair.

The Conference will deal broadly with the influence of design and operation factors upon the wear or consumption of refractories in foundries.

The first session, commencing on the afternoon of Thursday, 12th May, will be opened by Dr. W. J. Rees, and will deal with converter refractories. The second session, on the following morning, opened by Mr. W. J. Driscoll (British Cast Iron Research Association), will deal with cupola refractories and will include a paper by Mr. Bamford (The Austin Motor Company), on the water-cooling of cupolas. The third session, which will end early on the Friday afternoon, will be opened by Dr. G. Rigby (British Ceramic Research Association) and will deal with developments common to both.

Sixteenth Blast-Furnace Conference

The Sixteenth Blast-Furnace Conference on "Crushing, Screening, and Converging of Iron Ores," was held in London at Church House, Westminster, on 3rd and 4th May, 1949. Manufacturers of ore-handling equipment were invited. Each session was introduced by a representative of a manufacturing firm and a blast-furnace operator, and vigorous discussions ensued. New developments in ore-handling equipment were described.

Staff

Mr. R. H. MYERS, A.Met., F.I.M., died on 20th February, 1949, at Llay, Wrexham. Educated at Repton School and Sheffield University, he began his industrial career in the laboratory of the Rotherham melting shop of Messrs. Steel, Peech and Tozer, eventually becoming melting-shop manager. When the Templeborough melting shop of this firm commenced operations in 1917, Mr. Myers transferred to the basic furnaces there. Mr. Myers remained at Templeborough until 1930 when he joined the National Federation of Iron and Steel Manufacturers (which later became the British Iron and Steel Federation) as Open Hearth Research Officer. In this capacity he made a special study of ingot mould problems, and was Chairman of the Ingot Moulds Sub-Committee for many years. When the British Iron and Steel Research Association took over the research activities of the Federation in 1945, Mr. Myers was appointed Head of the Steelmaking Division of the new Association and held this position until he retired in June, 1948. He leaves a widow and one son.

NEWS OF SCIENCE AND INDUSTRY

Fourth Empire Mining and Metallurgical Congress

As already announced in earlier issues of the *Journal*, the Fourth Empire Mining and Metallurgical Congress, convened by the Empire Council of Mining and Metal-

lurgical Institutions, will be held in Great Britain from 9th to 23rd July, 1949.

The chief object of the Congress is to afford an opportunity for scientists, engineers, and others concerned with the mining and metallurgical industries, to meet and discuss technical progress and problems, including the development of the mineral resources of the Commonwealth.

The programme will be as follows :

July 9th to 12th, 1949—London

Inaugural Meeting, Government Reception, Banquet at Guildhall and a number of excursions and visits.

July 13th to 17th—Oxford

Technical Sessions. The main subjects for discussion will be : Mineral resources of the Commonwealth ; modern methods of prospecting ; physiological and psychological effects of heat and humidity on workers in deep mines and in metallurgical works ; petroleum (with special reference to the world oil position, oil-well drilling practice and its application to petroleum exploration) ; coal (with special reference to resources of the Commonwealth, the characteristics of Empire coals, and modern coal-mining practice in Great Britain) ; present-day trends in mineral dressing ; metallurgy and metallurgical industries.

July 18th to 23rd—Excursions

Visits based on Cardiff, Cornwall, Edinburgh, and Newcastle-upon-Tyne, will be made to collieries, iron and steel works, hydro-electric schemes, shipbuilding yards, and other places of technical interest, together with a number of excursions of historical and general interest.

Further information may be obtained on application to the Joint General Secretaries, Fourth Empire Mining and Metallurgical Congress, 436, Salisbury House, Finsbury Circus, London, E.C.2.

Mond Nickel Fellowships, 1949

The Mond Nickel Fellowships Committee invites applications for the award of Mond Nickel Fellowships, for the year 1949. Awards will be made to selected applicants of British nationality, educated to University degree or similar standard, though not necessarily qualified in metallurgy, who wish to undergo a programme of training in industrial establishments ; they will normally take the form of travelling Fellowships : awards for training at Universities may be made in special circumstances. There are no age limits, though awards will seldom be given to persons over 35 years of age. Each Fellowship will occupy one full working year. The Committee hope to award up to five Fellowships each year of an average value of £750 each.

Mond Nickel Fellowships will be awarded in furtherance of the following objects :

(*a*) To allow selected persons to pursue such training as will make them better capable of applying the results of research to the problems and processes of the British metallurgical and metal-using industries.

(*b*) To increase the number of persons who, if they are subsequently employed in executive and administrative positions in the British metallurgical and metal-using industries, will be competent to appreciate the technological significance of research.

(*c*) To assist persons with qualifications in metallurgy to obtain additional training, helpful in enabling them ultimately to assume executive and administrative positions in British metallurgical industries.

(*d*) To provide training facilities whereby persons qualified in sciences other than metallurgy may be attracted into the metallurgical field, and may help to alleviate the shortage of qualified metallurgists.

Applicants will be required to state the programme of training in respect of which they are applying for an award, as well as particulars of their education, qualifications, and previous career. Full particulars and forms of application can be obtained from The Secretary, Mond Nickel Fellowships Committee, 4 Grosvenor Gardens, London, S.W.1. Application forms should reach the Secretary of the Committee by 1st June, 1949.

Commemorative Plaque to Sir Robert A. Hadfield, F.R.S.

The unveiling of the commemorative plaque to Sir Robert Abbot Hadfield, F.R.S., took place on 12th March, 1949. The plaque is placed on the former residence of his father, at Attercliffe Common, Sheffield, where he was born. The son of Robert Hadfield, who was also distinguished for his work in the steel industry, Sir Robert was one of the foremost metallurgists of his generation. At the age of 24 he discovered manganese steel, and later silicon steel, and took a full share in the development of alloy steels generally. He took an active part in movements for the benefit of the University and City of Sheffield, he was Master Cutler in 1899, and was given the Freedom of the City of Sheffield. The plaque has been placed at the instigation of The Sheffield Metallurgical Association, The Sheffield Society of Engineers and Metallurgists, and The Iron and Steel Institute.

DIARY

5th May—LEEDS METALLURGICAL SOCIETY—Annual General Meeting and Students' papers—Chemistry Department, the University, Leeds—7.0 P.M.

6th–10th May—Summer Meeting Newcomen Society in Holland.

10th May—CHEMICAL ENGINEERING GROUP (Society of Chemical Industry)—"*Manufacture and Use of Stainless-Clad Steel*," by W. Barr—Geological Society, Burlington House, London, W.1, 5.30 P.M.

16th–19th May—INTERNATIONAL INSTITUTE OF WELDING—Annual Meeting—Delft, Holland.

18th–21st May—THE INSTITUTE OF PHYSICS—Convention and Annual General Meeting at Buxton.

25th May—THE INSTITUTE OF METALS—May Lecture by Sir Edward Appleton, F.R.S.—The Royal Geographical Society, 1, Kensington Gore, S.W.7, 6.0 P.M.

TRANSLATION SERVICE

(The previous announcement was made in the April, 1949, issue of the *Journal*, p. 370.)

TRANSLATIONS AVAILABLE

No. 377 (Russian). S. I. MASALOV : "The Production of Cold-Drawn Wire of Triangular Cross-Section." (*Katshestvennaia Stal*, 1938, No. 2, pp. 45–46).

CORRIGENDUM

Grain Growth in Si–Cr Valve Steel

The following corrections should be made to figures in the paper by H. Allsop and P. W. Bygate (*Journal of The Iron and Steel Institute*, 1949, vol. 161, April) :

Fig. 30(*a*) (Plate 7 between pp. 320 and 321) : The air-cooled temperatures should be as follows, reading from left to right, and from top to bottom : 900°, 1000°, 850°, 750°, 1050°, and 950° C.

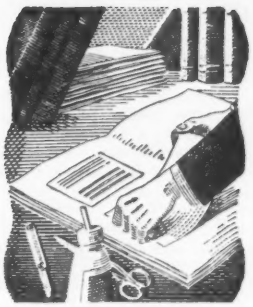
Fig. 32 (Plate 8 between pp. 320 and 321) : The left-hand photograph should illustrate high, and the right-hand low, initial temperature.

Fig. 34 (Plate 9 between pp. 320 and 321) : Right-hand marginal notes should read :

(1) "As water-quenched × 500
(2) Air-cooled—reheated 940–950° C. × 3
(3) Initial temperature, 1040–1050° C. Quenched to, and deformed at 750° C."

Left-hand marginal notes should read as above, but with initial temperature of 1110–1120° C.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES



IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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MINERAL RESOURCES

The Mineral Resources and Industries of the Commonwealth of Australia and the Mandated Territory of New Guinea. H. G. Raggatt, P. B. Nye, and N. H. Fisher. (Proceedings of the Australasian Institute of Mining and Metallurgy, 1946, Sept.–Dec., pp. 188–282). This is a comprehensive review of the mineral resources and industries of Australia and New Guinea in which minerals and metals are dealt with separately in alphabetical order.—R. A. R.

Refractory Slates of the Carboniferous Period. M. Budkiewicz. (Hutnik, 1948, vol. 15, May–June, pp. 237–238) [In Polish]. The Polish coal mines of the Krakow basin are described, and the occurrence of beds of refractory slates is noted.—W. J. W..

Contribution to the Study of the Oolitic Iron Ores of Lorraine (Briey Basin). Parts II and III. S. Caillère and F. Kraut. (Bulletin de la Société Française de Minéralogie, 1947, vol. 70, Jan.–June, pp. 22–48). Part II deals with Ottange ores and Part III with Hayange ores.

The Undeveloped Mineral Reserves of the Turkish Republic. E. P. Lorenz. (Mining and Metallurgy, 1948, vol. 29, Dec., pp. 654–657). Brief details are given of Turkish mineral resources, their location and extent. Iron ore deposits are known to exist in western and southern Anatolia but their exploitation has been much neglected. Turkish iron ores have a high iron content and it is anticipated that new iron deposits will be discovered as the basic geological conditions required for their formation are present.—J. C. R.

Analyses of Michigan, North Dakota, South Dakota, and Texas Coals. (United States Bureau of Mines, 1948, Technical Paper 700).

Properties and Utilization of the Siderite Ores of Bakal. L. M. Cylev. (Bulletin de l'Académie des Sciences, U.R.S.S., Classe des Sciences Techniques, 1947, No. 4, pp. 399–407 [in Russian]: [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 9, p. 1981). The points considered include the composition of the siderite ore, and the composition, quality, and defects of the iron and slags obtained when the siderite is mixed with other ores. The best composition of the mixture is deduced from the data obtained.

Notes and Résumé of Studies on Surigao Iron Ores. L. F. Abad. (Philippine Geologist, 1948, vol. 2, Sept., pp. 1–18). The extent and geology of the Surigao iron ore deposits at Mindanao (Philippines) are briefly reviewed with notes on the trials that have been made with it, and conclusions regarding the best plans for exploiting it are presented. This lateritic iron deposit containing 49% of iron, 0·75% of nickel, and 4% of chromium constitutes, perhaps, one of the greatest reserves in the world. It can be cheaply mined by modern open-cast methods and is favourably located for shipping.—R. A. R.

Geology and Chromite Deposits of the Camagüey District Camagüey Province, Cuba. D. E. Flint, J. F. de Albear, and P. W. Guild. (United States Department of the Interior, 1948, Geological Survey Bulletin 954-B).

ORES—MINING AND TREATMENT

Support of Ground, Iron Ore Mines, Lake Superior District. M. S. Petersen and F. E. Cash. (United States Bureau of Mines, 1948, May, Information Circular No. 7459).

Transportation of Iron Ore, Open-Cut Mines, Lake Superior District. J. A. Johnson and F. E. Cash. (United States Bureau of Mines, 1948, May, Information Circular No. 7458).

The Mechanism of Sintering of Iron Ores. P. E. Henry. (Publications de l'Institut de Recherches de la Sidérurgie, 1946, Series A, No. 1). The author's study of the mechanism of the sintering of iron ores (reference is also made to manganese ores) was based on small-scale experiments, visits to various sintering plants and the work of B. Hessle. (*Jernkontorets Annaler*, 1945, vol. 129, No. 8, pp. 383–446; *see Journ. I. and S.I.*, 1945, No. II, p. 175A, also Translation Series No. 289). Easy inspection and thorough sintering depend on the permeability of the mix and on thorough mixing, and means of achieving the desired characteristics are discussed. The factors influencing uniformity of ignition and the manner in which it can be attained, the influence of the composition of the gas used for ignition, the charging of the mix into the sinter pans, and the composition of the mix and the grain-size of its constituents are considered in detail. In a discussion of the mechanism of sintering, based on experiments in which blast-furnace dust was used, consideration is given to variations of the permeability of the bed and the temperature in the bed during sintering and the mineralogical composition of the sinter produced.—A. E. C.

Mobile Units for the Treatment of Ores and Coals in Dense Media. A. E. E. Goffinet. (Revue Universelle des Mines, 1949, Series 9, vol. 5, Jan., pp. 22–27). The principles and operation of mobile units for the treatment of ores and coals in dense media, are described. These units, which are prefabricated, can have a capacity of 5 to 40 tons/hr. The results obtained with three units, which use a media based on magnetite or ferrosilicon, are tabulated and discussed.

R. F. F.

Beneficiation of Ores by Electromagnetic Separation. V. Charrin. (Génie Civil, 1949, vol. 126, Jan. 1, pp. 11–12).

The theory of magnetic separation is discussed, and some types of separator are described.—R. F. F.

Report on a Journey to Sweden, Norway and Denmark—January, 1948. (Publications de l'Institut de Recherches de la Sidérurgie, 1948, Series B, No. 7). The Höganäs Works, the Söderfors Works, and the Hofors Works in Sweden were visited and the sintering process in use at the Hofors Works and the manufacture of sponge iron are discussed. Brief notes are made on ferrous metallurgy in Norway and iron manufacture in rotary furnaces in Denmark.—R. F. F.

New Dry Concentrating Equipment. W. J. Long. (United States Bureau of Mines, 1948, May, Report of Investigations No. 4286). Three new types of dry ore-separating machine are described. (1) The vibrating-deck separator is designed to separate flat from rounded or angular particles, *e.g.*, flaky graphite, molybdenite, and mica can be separated from quartz, feldspar, or other gangue materials. (2) The electrostatic shape separator combines sizing, shape separation, and separation according to differences in the electrical conductivity of particles. (3) The progressing field magnetic separator divides magnetic from non-magnetic particles of unsized ore; it is especially effective in the range of finer sizes.—R. A. R.

Concentration of Miscellaneous Oxide Manganese Ores from Yavapai, Yuma, Maricopa, and Mohave Counties, Ariz. W. J. Long, J. V. Batty, and K. C. Dean. (United States Bureau of Mines, 1948, June, Report of Investigations No. 4291). This report presents the results of tests to discover the best methods of concentrating low-grade manganese ores from four counties in Arizona.—R. A. R.

Concentration of Manganese Ores from Boulder Dam Recreational Area, Clark County, Nev. J. V. Batty and W. W. Agey. (United States Bureau of Mines, 1948, June, Report of Investigations No. 4302). This investigation of the Boulder area (Nevada) manganese ores showed that none of them was amenable to the production of high-grade manganese concentrates with appreciable recoveries.

Report on the Treatment of Iron Ores in the United States with a Note on English Tests on Magnetic Roasting. P. E. Henry. (Publications de l'Institut de Recherches de la Sidérurgie, 1948, Series B, No. 6). The author records his observations on American practice for iron ore treatments, which he noted during his visits to the United States. After briefly reviewing iron ore resources in the United States, he discusses crushing, beneficiation, and pyrometallurgy, including direct reduction and blast-furnace practice. Present tendencies and American research organizations are also discussed by the author who has appended a brief note on tests on magnetic roasting of jurassic oolithic ores which are in progress at the Scunthorpe Works of the Appleby-Frodingham Steel Co.

R. F. F.

FUEL—PREPARATION, PROPERTIES, AND USES

Heat Balances for Iron and Steel Manufacture. G. Grenier. (Echo des Mines, 1948, Oct., pp. 196–197; Nov., pp. 218–219; Dec., pp. 236–237; 1949, Jan., pp. 9–10). The heat balances for the various operations in the production of iron and steel are discussed.—R. F. F.

Methods for Determining the Total Radiation of Carbon Dioxide and Steam in Industrial Heating. C.-A. Landfermann. (Stahl und Eisen, 1949, vol. 69, Feb. 3, pp. 98–99). The radiation of carbon monoxide and hydrogen in gaseous fuels such as blast-furnace gas and coke-oven gas has hitherto been determined empirically and no account was taken of the different effects on the two gases of temperature, partial pressure, and layer thickness. The author makes use of physical relationships and laws to develop a theoretical method which takes the above points into account.—R. A. R.

A Method of Calculating the Temperature Distribution in Non-Uniformly Heated Tubes. F. Salzmann. (Seventh International Congress of Applied Mechanics, London, Sept. 1948: [Abstract] Journal of the British Shipbuilding Research Association, 1948, vol. 3, Oct., p. 465). The paper discusses the temperature distribution in a tube-cross-sectional area for the distribution of heat transfer through the tube wall to a gaseous medium flowing within, as occurs in the practical cases of heat exchangers, gas heaters, etc. Two main cases are dealt with, both of which are common in cross-current designs. The first case is that of a tube subjected to external radiation, and the method derived is then extended to cover a second case where an actual flow takes place across the outer surface and with the heat transfer coefficient from fluid to tube wall varying in value around the tube periphery. The flow in the direction of the tube axis is neglected. The temperature levelling effects of the circumferential heat flow in the wall and of the interradiation at the inner surfaces are quantitatively demonstrated. For the purpose of direct calculation, a number of tables and curves are included. The method is demonstrated with some numerical examples of the temperature distribution in an air-heater tube, and the results of the calculations are found to be in sufficient agreement with those obtained by experiment.

Coal Preparation Plant at Dunaskin. (Iron and Coal Trades Review, 1949, vol. 158, Jan. 21, pp. 107–114). A detailed, illustrated description is given of the washing and coal-treatment plant, erected at Dunaskin in Ayrshire, which includes a slurry flocculation section. Operational results are given.—J. C. R.

Heat Conditions in the Walls of Coke-Oven Chambers. B. I. Kustov and A. I. Voloshin. (Ogneupory, 1948, vol. 13, p. 79: British Ceramic Abstracts, 1948, Sept., p. 289A). The surface temperature of the lining of a coke-oven chamber falls rapidly after the oven has been charged. In the ovens under study it fell from 1000° C. to 500–600° C. in 2 hr. It is essential that the temperature of the walls should be as high as possible before charging in order to prevent the lining cooling below the inversion point of silica.

Tracer Study of Sulphur in the Coke Oven. S. E. Eaton, R. W. Hyde, and B. S. Old. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2453: Metals Technology, 1948, vol. 15, Oct.). In this investigation a small amount of iron pyrites was prepared from radio-active sulphur, and mixed thoroughly with the coal charge to one full-scale coke oven, and the mixture coked under normal conditions. The course of the pyritic sulphur was traced to determine the quantity evolved in the gas and the quantity remaining in the coke. Results of tests indicated that sulphur remains in coke without regard to the form originally present in the coal, and consequently there would be no advantage in choosing coal for its high or low pyritic or organic sulphur content. In order to produce low-sulphur coke, coals low in total sulphur must be used.

J. C. R.

Statistics of Chemical and Physical Characteristics of Various Metallurgical Cokes Used in France and Some Foreign Countries from 1934 to December 1947. C. G. Thibaut. (Publications de l'Institut de Recherches de la Sidérurgie, 1948, Series A, No. 3). The statistics given are for French, Belgian, German, Saar, Dutch, and British cokes.—R. F. F.

TEMPERATURE MEASUREMENT AND CONTROL

A Radiation Pyrometer for Low Temperatures. F. E. Hessey. (Steel Processing, 1948, vol. 34, Dec., pp. 644–648). A detailed description is given of the Radiamatic pyrometer for temperatures in the 100–600° F. range. It has three components, the receiving instrument containing a group of small thermocouples on which a lens focuses the radiation, a reference junction temperature controller, and an electronic potentiometer. The instrument has a rapid response and can be used for measuring the temperature of moving objects.

R. A. R.

The Development and Present Position of Metallurgical Metering Techniques Abroad in the Last Ten Years. K. Guthmann. (Stahl und Eisen, 1949, vol. 69, Jan. 6, pp. 8–18). Development in the U.S.A. and Great Britain in the design and use of equipment for measuring heat flow and temperature for metallurgical purposes are reviewed.—R. A. R.

Thermocouple for Measuring the Temperature of the Steel Bath. V. G. Gruzin. (Zavodskaya Laboratoriya, 1948, vol. 14, Nov., pp. 1396–1397). [In Russian]. A brief account is given of the construction, calibration, and method of operation of a platinum/platinum-rhodium thermocouple for use with molten steel.—S. K.

REFRACTORY MATERIALS

A New Method for Controlling the Composition of a Fired Clay Body. P. S. Mamikin and B. A. Loshkarev. (Ogneupory, 1948, vol. 13, p. 127: British Ceramic Abstracts, 1948, Sept., pp. 294A–295A). The usual method of determining

the quality of grog in a fired clay body entails placing a suspension of the material in a sieve, through which the grog particles can fall, Owing to the difficulty of obtaining the necessary sieves in the U.S.S.R. other methods frequently have to be used. The most satisfactory method is that in which a suspension of the material is placed in a measuring cylinder with an electrolyte. The grog settles and can be measured while the clay remains in suspension.

Improvement of Analytical Control for Silica Brick. J. T. Rozsa. (Journal of the American Ceramic Society, 1948, vol. 31, Oct. 1, pp. 280–283). A method of spectrographic analysis developed for the control of silica bricks is described. The accuracy of this method is within 5% and the time required is about 1 hr.—R. F. F.

Laboratory Tests of Dolomite from the Timoshkino Deposits. V. A. Rybnikov. (Ogneupory, 1947, vol. 12, No. 5, pp. 203–205 : American Ceramic Abstracts, 1948, Oct. 1, pp. 224–225).

The Production of Ladle Bricks from Compositions Containing Nevyan Kaolin. D. I. Gavrish and C. P. Zegzhda. (Ogneupory, 1948, vol. 13, p. 99 : British Ceramic Abstracts, 1948, Sept., p. 288A). Fired clayware with low porosity is made from vitrified clay in Ural factories by adding Nevyan kaolin. The ware contains Belkin clay, Nizhny-Uvel clay, and about 35 % Nevyan kaolin, and has high spalling and slag resistance.

Refractory Plastic Chromite Masses. L. A. Tseitlin. (Ogneupory, 1947, vol. 12, No. 5, pp. 216–221 : American Ceramic Abstracts, 1948, Oct. 1, p. 225). Chromite ore from the Saranov deposits containing 37·1% Cr_2O_3 was used to make plastic masses with Chasov Yar clay and 5%, 7%, and 10% soluble glasses (in excess of 100%), which were dried at 110° C. These were fired at temperatures up to 1350° C. Charges containing (*a*) 97% ore and 3% Chasov Yar clay with 7% (in excess of 100%) soluble glass and (*b*) 100% chromite and 7% soluble glass and fired at 1350° C. had, respectively, shrinkages of 2·1% and 2·2%, apparent porosities of 10·6% and 11·3%, compressive strength of 340 and 360 kg./sq. cm., initial deformation at 1180° and 1150° C., and were completely destroyed at 1260° and 1340° C. under a load of 2 kg./sq. cm. In both cases the refractoriness was over 1900° C. Mass *b* was used in open-hearth furnaces and lasted fifty-two heats. The behaviour of the product in service was the same as that of an imported American plastic product, but the American material lasted longer under the same conditions.

Investigation of Abrasion Resistance of Various Refractories. K. A. Baab and H. M. Kraner. (Journal of the American Ceramic Society, 1948, vol. 31, Nov. 1, pp. 293–298). An accelerated abrasion test for refractories is described. In this test, the specimen bricks are sand-blasted with silica sand. Twenty-three brands of bricks were tested by this method and the results are tabulated and correlated with the results of tests on the other standard physical properties.
R. F. F.

Physical Chemistry of Alumina Refractories. R. L. Pevzner and A. S. Berezhnoĭ. (Zhurnal Prikladnoy Khimii, 1947, vol. 20, No. 10, pp. 938–952 : American Ceramic Abstracts, 1948, Nov. 1, pp. 245–246).

Deformation of Fireclay Ware under Load at Various Temperatures. D. N. Poluboyarinov and G. G. Feldgandler. (Ogneupory, 1948, vol. 13, p. 1071 : British Ceramic Abstracts, 1948, Sept., p. 286A). The deformation of refractory material under load at a certain temperature depends on its apparent viscosity at that temperature. A study is made of eight types of firebrick in common use in the U.S.S.R. They were tested under a load of 28 lb./sq. in., and the results, given in a tabular form, show the temperature at which deformation begins and the temperature at which 4%, 10%, and 40% subsidence occurs. Voroshilov standard firebrick and Semiluk blast-furnace bricks have the highest resistance, showing no deformation until 1370° and 1390° C. respectively, and 10% subsidence at 1550° C.

Sonic Method for Determining Young's Modulus of Elasticity. K. A. Baab and H. M. Kraner. (Journal of the American Ceramic Society, 1948, vol. 31, Nov. 1, pp. 318–320). The instrument and methods for measuring the resonant frequencies of brick and for calculating Young's Modulus of elasticity are described. Charts correlate elasticity and other properties of fired bricks with firing temperatures. Results indicate that the sonic method of determining the modulus of elasticity is suitable for determining the degree of firing that a series of brick has undergone.

Use of Uktus Dunite as Repair Material. I. Sh. Shvartsman. (Ogneupory, 1947, vol. 12, No. 6, pp. 276–281 : American Ceramic Abstracts, 1948, Oct. 1, p. 225).

Wear of Refractories during Steel Casting. M. C. Kamenichny. (Ogneupory, 1948, vol. 13, p. 73 : British Ceramic Abstracts, 1948, Sept., p. 288A). Low-carbon steel is cast at about 1600° C. whereas high-carbon steel can be cast at 1500° C. Fireclay refractories are most corroded by steels which are cast at high temperatures. This is due to metallic oxides, MnO and FeO, which are absorbed by the refractories from the metal and from the basic slag crust.

The Development of Refractories for High Temperature Industrial Processes. A. Hilliard and J. H. McKee. (Refractories Journal, 1948, vol. 24, Mar., pp. 98–105 ; Apr., pp. 134–136). This paper describes the physical and chemical properties of siliceous and alumino-siliceous refractories, and comments upon high-porosity acid and basic refractories and aluminous cements.—J. P. S.

Silica and Fire Clay Refractories for Steel Plant Furnaces. C. A. Brashares. (Iron and Steel Engineer, 1948, vol. 25, Dec., pp. 49–53). The applications of super-duty silica bricks and fireclay refractories in steel furnaces are discussed.
J. C. R.

A Fireclay Brick for Suspended Furnace Roofs. D. S. Rutman. (Ogneupory, 1948, vol. 13, p. 69 : British Ceramic Abstracts, 1948, Sept., p. 286A). A description is given of a ribbed brick for use in suspended roofs. The ribs enable the bricks to be fitted tightly together so as to prevent hot gases escaping from the furnace ; they also prevent the bricks from falling.

BLAST-FURNACE PRACTICE AND THE PRODUCTION OF PIG IRON

Blast Furnace Lines. E. Mazanek. (Hutnik, 1948, vol. 15, Apr., p. 158). [In Polish]. Different types of blast-furnace profile are discussed from metallurgical points of view.
W. J. W.

Some Correlations between Variables Affecting Sulphur in Blast-Furnace Iron. T. E. Brower and B. M. Larsen. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2465 : Metals Technology, 1948, vol. 15, Oct.). Operating data from several commercial blast-furnaces are evaluated to determine the effect of manganese on sulphur elimination under operating conditions. Certain other variables such as silicon in iron, and slag basicity, which are in part interrelated, are included. One of the conclusions reached is that manganese in iron has an important effect on both the sulphur in the iron and on the ratio of the sulphur in the iron to the sulphur in the slag. Under certain conditions the manganese in the iron may be the main determining factor. Moisture content of the blast appears to have a direct positive effect on desulphurization in addition to its indirect negative effect through lowering of hearth zone temperature.—J. C. R.

Practical Considerations of Some of the Factors Having an Influence on the Quantity of Coke Consumption per Metric Ton of Pig Iron in the Blast Furnaces of the Briey Basin. M. Brun. (Iron and Steel Institute, 1949, Translation Series, No. 373). This is an English translation of a paper which appeared in Revue de Métallurgie, Mémoires, 1945, vol. 42, Sept., pp. 273–285 ; Oct., pp. 308–320 ; Nov., pp. 347–358 ; Dec., pp. 393–401. (*See* Journ. I. and S.I., 1948, vol. 158, Mar., p. 395).

DIRECT PROCESSES

Study of the Equilibria of Reduction of Calcium Ferrites and Brownmillerite with Carbon Monoxide. G. Malquori and V. Cirilli. (Iron and Steel Institute, 1949, Translation Series, No. 375). This is an English translation of a paper which appeared in Gazetta Chimica Italiana, 1945, vol. 75, Aug.–Sept., pp. 137–156. The authors investigated the reduction equilibria of brownmillerite ($4CaO.Al_2O_3.Fe_2O_3$) and of two calcium ferrites ($2CaO.Fe_2O_3$ and $CaO.Fe_2O_3$) with carbon monoxide at temperatures of 900°, 1000°, 1050°, and 1100° C. With all three compounds the reduction takes place in a manner quite different from that observed for ferric oxide alone. Reduction of brownmillerite and dicalcium ferrite produces metallic iron without passing through the ferrous phases, but with monocalcium ferrite new compounds are formed during decomposition, namely, $CaO.Fe_2O_3$

and $CaO.3FeO.Fe_2O_3$. The brownmillerite had the greatest stability.—R. A. R.

Utilization of Domestic Low-Grade Iron Ores. K. Radzwicki. (Hutnik, 1948, vol. 15, Apr., pp. 153–157). [In Polish]. Experiments in the utilization of low-grade Polish iron ores are described. By means of the Krupp-Renn process a product suitable for use in the open-hearth and electric furnaces has been made.—W. J. W.

PRODUCTION OF STEEL

Theory of the Modern Open-Hearth Furnace. W. Kuczewski. (Hutnik, 1948, vol. 15, May–June, pp. 205–212). [In Polish]. Different types of open-hearth furnace are shown and their characteristics discussed.—W. J. W.

Present Methods of Open-Hearth Furnace Charging. E. L. Diamond and A. M. Frankau. (Journal of The Iron and Steel Institute, 1949, vol. 161, Mar., pp. 191–211). The present methods of supplying material to open-hearth furnaces have approached their limits, whereas chargers, if not required to charge more than one furnace at a time, have a good margin above the capacity to melt, of all but the very largest furnaces. The fixed charger has a net advantage in speed over the rotating type of only about 20%, because it is interrupted when empty trains of scrap bogies are replaced. To obtain the shortest melting time it is preferable to charge at a steady rate, and therefore to have as many chargers as the maximum number of furnaces to be charged simultaneously at the maximum rate of charging. If this is taken to be half the number of furnaces installed, the theoretical loss of output is negligible and is offset by other limitations.

From this starting point, the capacities of bench loading and stage railway supply systems have been analysed on the basis of furnace frontage and capacity, using data obtained from extensive time studies. If the magnet cranes could be relieved of the duty of replacing empty pans by full pans, the bench system would have ample capacity for any melting shop at present contemplated. Suggestions to this end are put forward. Stage railway systems are limited by congestion and by mutual interference of train movements, and detailed study of the working of such systems, both in practice and by charts and models, suggests that centralized traffic control on the lines indicated will be essential to attain the full capacity of such systems for very large shops. The delivery of raw materials by conveyor and bunker increases the capacity of both systems, but especially that of stage railway systems, on account of the disproportionate amount of shunting involved in feeding the raw materials to the chargers in the right sequence.

The Influence of Heat Transfer on Open-Hearth Furnace Charging Rate. M. W. Thring. (Journal of The Iron and Steel Institute, 1949, vol. 161, Mar., pp. 212–221). Model experiments and calculations were used to decide whether increase in the rate at which the charge can be inserted into an open-hearth furnace will give an improvement in the total melting time. The model consisted of paraffin wax melted by a constant radiation from above and showed that assessment of the time to melt the charges below the liquid surface is not a fair way of assessing the merits of different charging schedules; only the time for complete melting can be used. A theoretical analysis then showed that for a given gross downward radiation the shortest possible melting time is obtained when the heat never has to pass through a thermal resistance before being absorbed as temperature rise. This means that it is of no advantage to put in the charge faster than the heat-transfer will permit, and in fact in some cases putting it in too fast can cool the furnace excessively and so reduce the gross downward radiation. If the charging must be stopped at any point before all the charge is inserted, because the furnace is becoming too full, or too cold, then the heat-transfer rate is the bottleneck. If, on the other hand, it is necessary to reduce the fuel-input rate from the maximum during the charging period then the charging is too slow. The latter usually occurs only when there is a delay in the arrival of materials, but if new furnaces are designed with a larger bath area per unit weight or with more rapid combustion rates, this state may be reached more frequently. The ideal charging process is uniform insertion at a rate such that the roof is kept always just below the maximum safe value while the fuel is being burnt at the maximum rate.

In one appendix J. P. Simons gives full details of the experimental procedure for melting paraffin wax in a basin underneath an electric resistance heater, and in another appendix L. Daws explains the calculation of the time required to heat and melt steel in an open-hearth bath.

Proper Utilization of Alloy Steel Scrap. K. Radzwicki. (Hutnik, 1948, vol. 15, July–Aug., pp. 300–303). [In Polish]. The economic utilization of alloy steel scrap is discussed and efficient methods are proposed. High-frequency furnaces are shown to be the best for the remelting process.—W. J. W.

The Complete Deoxidation of Steel with Aluminium. J. G. Platon. (Revue de Métallurgie, Mémoires, 1948, vol. 45, Dec., pp. 512–514). After comparing the steel-deoxidizing properties of manganese, silicon, and aluminium, the author describes efforts made in France during the war to use more aluminium to kill steels, in order to use less manganese which was in short supply, and gives a short account of the difficulties met with and the results achieved.—A. E. C.

Electrolytic Manganese in Open-Hearth and Bessemer Steel Tests at Jones & Laughlin Steel Corp., Pittsburgh, Pa. F. Sillers, jun. (United States Bureau of Mines, 1948, July, Report of Investigations No. 4303). Tests have been made on a laboratory scale and on a full production scale to study whether the use of electrolytic manganese instead of ferromanganese had any detrimental effect when making (*a*) 0·35% carbon steel, (*b*) low carbon rimming steel for strip, (*c*) low carbon killed steel, and (*d*) two grades of Bessemer screw steel. With (*a*) slightly higher elongation and lower tensile strength were observed. With (*b*) no appreciable difference in physical properties was recorded. As to (*c*) no appreciable or consistent differences in surface quality of the semi-finished products were observed, but costs of production were over $1/ton higher with electrolytic manganese. As to (*d*) the manner in which the electrolytic manganese was added, and the fact that there was no protecting and compensating carbon in the addition, caused the eleven heats of Bessemer screw steel made with electrolytic manganese to show lower average efficiency of recovery and more rejections on scarfing the billets than the eleven heats made with ferromanganese.—R. A. R.

An Electrical Pressure Meter for the Measurement of Open-Hearth-Furnace Differential Pressures. S. S. Carlisle and B. O. Smith. (Journal of The Iron and Steel Institute, 1949, vol. 161, Mar., pp. 222–229). The paper describes a sensitive electrical differential-pressure meter developed in the Physics Laboratories of the British Iron and Steel Research Association for measurement of open-hearth-furnace differential pressures (0 to $\pm$ 0·1 in. W.G.) The design and construction of the instrument is such that it can be installed close to the measuring point on the roof of the furnace; thus, the errors normally arising from buoyancy effects in long pressure pipes are eliminated. It is specifically designed for remote indication, the pressure differential being measured in terms of an electrical current, which can be indicated or recorded on a normal moving-coil meter situated at any distant position.

The operating principle is that the force on a freely mounted diaphragm, resulting from the applied differential pressure, is automatically balanced by the force developed by a current-carrying coil moving in a fixed magnetic field. At equilibrium the current in the coil is a direct measure of the force produced, and thus of the applied pressure. This 'null' method of measurement ensures a high stability of calibration of the instrument, and freedom from wander of the zero reading.

Some Practical Features of Oxygen in Steelmaking. A. G. Arend. (British Steelmaker, 1949, vol. 15, Jan., pp. 22–24). Economic aspects of the use of oxygen in steelmaking are discussed. Savings in transport charges by substituting liquid for compressed oxygen are pointed out. Unless the consumer requires a minimum of 500,000 cu. ft. per month, small generating plants which occupy 100 sq. ft. of floor space are not practical. Experience with oxygen at some American and Canadian Steelworks is cited.—R. A. R.

Oxygen in Steelmaking. W. Mann. (Scientific American, 1948, vol. 178, Feb., pp. 53–56: [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 9, p. 1982). This article deals with the increased use of oxygen in steelmaking whereby temperatures can be attained which facilitate reactions between the metal and slag. The possibility of using lean ores is discussed.

A Compressed Air Circuit Breaker for 23-kV. Arc Furnace Duty. H. M. Wilcox and B. P. Baker. (Transactions of the American Institute of Electrical Engineers, 1948, vol. 67. Part I, pp. 154–158).

A 10,000-kVA. Series Capacitor Improves Voltage on 66-kV. Line Supplying Large Electric Furnace Load. B. M. Jones, J. M. Arthur, C. M. Stearns, and A. A. Johnson. (Transactions of the American Institute of Electrical Engineers, 1948, vol. 67, Part I, pp. 345–354). The largest kilovolt-ampère and highest voltage-series capacitor in the world was placed in service in 1947 to improve voltage regulation and alleviate voltage flicker at the Crucible Steel Company and on the line serving this works. The reasons for selecting the series capacitor and some design considerations are given.—R. A. R.

Experimental Production of Ball-Bearing Steel. M. Stankiewicz, T. Masior, and S. Rogowski. (Hutnik, 1948, vol. 15, May–June, pp. 213–226). [In Polish]. The manufacture of steels for ball bearings, in the basic electric furnace, and in high-frequency furnaces, is described. Distribution of inclusions was studied by micro-examination and by "blue fractures," a method standardized by Metallurgical Standards (Normy Hutnicze C.Z.P.H., BM-31).—W. J. W.

Melting Practice for Ball-Bearing Steels. M. Stankiewicz, T. Masior, and S. Rogowski. (Hutnik, 1948, vol. 15, Apr., pp. 165–169). [In Polish]. Polish and foreign melting practices for ball-bearing steels are discussed and compared.—W. J. W.

Considerations on the Removal of Phosphorus in the Basic Electric Furnace. C. Brudaschia. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, July, pp. 442–451 :[Abstract] Chimie et Industrie, 1949, vol. 61, Jan., p. 50).

Effect of Some Melting Variables on the Tensile Properties of Acid Electric Steel. S. F. Carter. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference, Dec. 4–6, 1947, Proceedings, vol. 5, pp. 182–202). Statistical analyses have been made from test data on the effects of altering one variable at a time in acid electric-furnace melting practice. The paper is based to some extent on an earlier one by S. F. Carter and C. K. Donoho (*see* Journ. I. and S.I., 1947, vol. 157, Sept., p. 143). The principal conclusions were : (1) Slightly oxidizing conditions should be maintained during melting ; (2) as soon as melted, a high concentration of iron oxide should be produced in order to lower the silicon and manganese, make the inclusions fluid and get rid of hydrogen ; (3) there is no physical advantage in forcing the carbon extremely low ; (4) the slag should be moderately oxidizing and the heat kept slightly boiling while the carbon is adjusted and the slag is forming ; (5) for the first deoxidizing addition, manganese and silicon together are better than either alone ; they should be added in time to complete their reactions before aluminium is introduced so as to minimize the aluminium oxide inclusions ; and (6) a slag either extremely oxidizing or extremely reducing lowers the ductility of the steel.—R. A. R.

Recovery of Vanadium and other Alloys in the Acid Electric Furnace. C. Wyman and G. W. Johnson. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference, Dec. 4–6, 1947, Proceedings, vol. 5, pp. 203–227). Analyses of metal and slag were made at various stages in 24 heats, including manganese–molybdenum–vanadium steel, manganese–chromium steel, and carbon steel, to study the movement of the vanadium. It was evident that 80–90% of the vanadium in the vanadium-bearing scrap can be recovered by controlling the FeO in the finishing stages of the heat. The uniformity of the FeO content of the slag in the finishing period, and especially at tapping, affects the mechanical properties of the finished steel. There is evidence that maintaining a high carbon content at melt-down, and subsequently, effectively controls the FeO in the bath, thus retarding the oxidation of the residual alloying elements. The more active a slag can be kept during the working of a heat, the cleaner will be the steel on tapping. R. A. R.

Review of Known Factors Controlling Slag Volume. C. Locke. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference, Dec. 4–6, 1947, Proceedings, vol. 5, pp. 228–234). The literature on factors affecting slag volume in electric furnace steelmaking practice is reviewed. There are thirteen references.—R. A. R.

Effect of Bottom Shape and Life on Slag Volume in Acid Electric Furnace. J. A. Bowers. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference, Dec. 4–6, 1947, Proceedings, vol. 5, pp. 235–238). The slag formed when making steel in two 2-ton top-charge acid electric furnaces was weighed at frequent intervals during the furnace life, and the results were plotted to see if any correlation could be established between the quantity of the slag and the number of heats, the change in furnace dimensions, the weight of slag-making materials charged, and the manganese loss. The following tendencies could be observed : (*a*) More slag with increasing number of heats ; (*b*) more slag with increasing furnace diameter ; and (*c*) greater manganese loss with more slag.—R. A. R.

Effect of Extent of Bottom Repairs on Slag Volume in Acid Electric Furnace. J. D. Cannon. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference, Dec. 4–6, 1947, Proceedings vol. 5, pp. 238–241). Data are presented on the weight of slag in a large number of heats making plain carbon steel in a 3-ton acid electric furnace, as well as on the quantity of material used for patching the lining below the slag line, and the manganese recovery. The amount of patching material did not affect the weight of slag, and the manganese recovery was greater the smaller the amount of slag.—R. A. R.

Effect of Bank Repairs on Slag Volume in Acid Electric Steelmaking. F. B. Eiseman. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference, Dec. 4–6, 1947, Proceedings, vol. 5, pp. 241–242). Data on slag volumes and materials used for repairing the hearth and banks of a 3½-ton acid electric furnace are presented. They indicate that the repairs have no significant effect on the quantity of slag or its composition.—R. A. R.

Effect of Cleaned *vs.* Uncleaned Foundry Scrap on Slag Volume. W. L. Doyle. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference, Dec. 4–6, 1947, Proceedings, vol. 5, pp. 243–244). Data are presented on the calculated volume of slag produced in four 6-ton acid electric furnace heats in some of which the scrap charged was shot-blasted, and in others it was not. The volume of slag was, however, affected by other factors in the melting practice.—R. A. R.

Effect of Metal Depth on Slag Volume in Electric Furnace. M. T. McDonough. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference, Dec. 4–6, 1947. Proceedings, vol. 5, p. 245). Some tests on heats in 6 and 8-ton acid electric furnaces showed that there was no relation between metal depth and slag volume.—R. A. R.

Effect of Tap Changes on Slag Volume in the Electric Furnace. D. B. McDyre. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference, Dec. 4–6, 1947, Proceedings, vol. 5, pp. 246–248). Four heats of similar 0·26–0·30% carbon steels were made in a 1½-ton acid electric furnace using 8-in. electrodes and a 2000-kVA. transformer with four tappings. The practice was almost identical in each case except for differences in the tappings used. The quantities of slag produced in lb./ton of steel were : (1) With 195, 150 and 130 V. tappings, 104 lb. ; (2) with 195 V. throughout the heat, 20·2% more than (1) ; (3) using 195 V. until the boil and then 130 V., 11·4% less than in (1) ; and (4) using 150, 130, and 113 V., 36·2% more than in (1). There was very little difference in the total amount of power used in each case.—R. A. R.

Effect of Temperature and of Basic Additions on Slag Volume in the Electric Furnace. J. B. Caine and G. R. McDaniels. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference, Dec. 4–6, 1947, Proceedings, vol. 5, pp. 248–254). Data are presented on the weights of charge, additions, and slags relating to nine 5-ton heats of electric furnace steel tapped at 3200° to 3250° F. and eleven heats tapped at 2960° to 3040° F. The average total weight of slag in the colder heats was 935 lb. against 715 lb. for the others, but more slag-making additions were used with the former. The proportions of slag coming from the lining were 40% and 54% for the colder and hotter heats respectively. Different dolomite additions were made to the finishing slags of the eleven colder heats, but with from 10% to 19% of CaO + MgO in these slags the total slag volume was approximately the same.—R. A. R.

Effect of Manganese Ore on Slag Volume. C. C. Spencer. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference, Dec. 4–6, 1947, Proceedings,

vol. 5, pp. 254–255). Data relating to the slags from four series of 5-ton electric furnace steel heats are presented to show the effect of different additions of manganese ore. The results were : (1) With 24 lb. of manganese ore and 35 lb. of limestone, an average of 518 lb. of slag for five heats ; (2) with 52 lb. of manganese ore and 35 lb. of limestone, 864 lb. and 915 lb. in two heats ; (3) with 26 lb. of manganese ore before iron ore additions, and 52 lb. after the carbon boil, and 15 lb. of iron ore, 930 lb. and 920 lb. in two heats ; and (4) with 26 lb. of manganese ore at meltdown and 52 lb. after the carbon boil, 910 lb. and 925 lb. in two heats.—R. A. R.

Effect of Time of Heat on Slag Weight in the Electric Furnace. R. H. Frank. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference, Dec. 4–6, 1947, Proceedings, vol. 5, pp. 255–256). Data on seven heats of electric furnace steel are presented which show that there is no relation between heat time and slag volume. There is some evidence that the manganese recovery decreases with increasing quantities of slag.—R. A. R.

Fundamental Electric Terms. A. R. Oltrogge. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference, Dec. 4–6, 1947, Proceedings, vol. 5, pp. 261–267). This paper was one of two in a Session on " Fundamentals of Electricity for the Melter." A number of technical terms relating to the measurement of electricity which are used in electric furnace practice are simply explained. R. A. R.

Operation of the Panel Board of an Electric Furnace. F. W. Cramer. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference, Dec. 4–6, 1947, Proceedings, vol. 5, pp. 267–280). This is the second paper in the Session on " Fundamentals of Electricity for the Melter." The components of a control panel for electric steel furnace operation are described and their functions explained. Descriptions are also given of transformer construction, safety devices, watt meters, circuit breakers, etc. R. A. R.

Core Problems in the Conversion of Energy in Large Electric Melting Furnaces. J. Wotschke. (Schweizer Archiv, 1948, vol. 14, Oct., pp. 299–306). The zones in electric resistance and arc furnaces where the conversion of energy is concentrated are considered with special reference to an arc furnace 10 m. in dia. with seven electrodes, taking an average load of 30,000 kW. and producing 200 tons of calcium carbide per day.—R. A. R.

The Application of Metallurgy to Aircraft Design. L. Schapiro. (Inst. Aero. Sci., July 1948, Reprint No. 153 : [Abstract] Index Aeronauticus, 1949, vol. 5, Feb., p. 42). The author discusses the principles of producing high-strength ferrous and non-ferrous metals, mainly aluminium alloys and steel. Brief mention is also made of high-melting-point metals such as molybdenum, and their melting by electric arc in a vacuum.

A Statistical Investigation of Cracking in Basic Open-Hearth Ingots. I. M. Mackenzie and A. J. Donald. (West of Scotland Iron and Steel Institute, Jan., 1949, Preprint). The statistical methods referred to in an earlier paper (*see* Journ. I. and S.I., 1948, vol. 160, Oct., p. 221) have been applied to study the variables affecting the incidence of cracking in ingots of two qualities of basic open-hearth steel, namely, (*a*) mild steel with C 0·18–0·22%, and (*b*) En 16 steel with C 0·33–0·37%, Mn 1·45–1·6%, Ni 0·30% max., Cr 0·20% max., and Mo 0·30–0·35%. The method of multiple graphical correlation, which is described, was used. The most important factors contributing to the variance of the cracking index were found to be tapping temperature, temperature during refining, phosphorus and sulphur contents of the metal, and teeming speed. Experimental data for the hydrogen content during refining are given, and it is suggested that hydrogen is an important factor in rolling quality. Values for the temperature drop during tapping are shown and the shape of the regression lines of cracking on tapping temperature is explained.—R. A. R.

FOUNDRY PRACTICE

Calculation of the Time a Metallic Charge has to Remain in the Cupola Melting Furnace. M. Czyževski. (Hutnické Listy, 1948, vol. 3, Nov., pp. 330–334). [In Czech]. Formulæ are presented for calculating the time and amount of heat required to melt a metal charge in the cupola. These are derived from existing formulæ given by other authors and from an equation for calculating the heat-transfer coefficient from gases to the metal. In melting experiments with hexagonal pieces of various sizes (30 to 130 mm.) in a cupola with an inside diameter of 0·5 m. the author found that heating to the melting temperature required between 22 and 23 min. and the melting took a further 2 to 9 min. The calculated times were 10 to 29 min. and 1·8 to 8 min. respectively, according to the size of the pieces in the charge. In some other cases there was a considerable discrepancy between the times obtained by calculation and those obtained experimentally. E. G.

Considerations on the Design of Castings. P. Prette. (Revue Générale de Mécanique, 1949, vol. 33, Feb., pp. 53–62). General casting principles are discussed as a guide to the design of castings.—R. F. F.

Casting Stainless Steel Centrifugally. H. J. Cooper. (Iron Age, 1949, vol. 163, Jan. 27, pp. 56–59). Rings up to 27 in. in dia. are being centrifugally cast in a heat-resisting alloy (24% Cr, 12% Ni, and 3% W), for use in the American version of the Rolls-Royce Nene jet engine. Vertical spinning is employed with moulds of steel SAE 4130 (C 0·28–0·33%, Mn 0·40–0·60%, Cr 0·80–1·10%, Mo 0·15–0·25%). After casting, cleaning, and rough-machining, the rings are X- or gamma-rayed.—J. P. S.

Graphitisation in the Malleable Process. H. G. Hall. (Foundry Trade Journal, 1949, vol. 86, Jan. 20, pp. 55–57). This is a summary of a paper presented to the Association Technique de Fonderie. The author reviews the present state of knowledge on the mechanism of graphitization in malleable iron, including factors which affect the rate of graphitization and the effects of alloying and residual elements and of the raw materials in the melting furnace charge. The production of thin-section malleable castings, capable of being machined at high speeds, using an oil-fired rotary furnace, is mentioned. J. C. R.

Formation of Peel on Whiteheart Malleable Cast Iron. F. Bischof. (Neue Giesserei, 1949, vol. 36, Jan., pp. 19–22). The literature on peel formation on whiteheart malleable cast iron is critically reviewed.—R. A. R.

Study of Moulding and Core Sands. J. Happich. (Fonderie, 1948, Sept., pp. 1316–1320). An account is given of the characteristics of moulding sands in use at a French works, and the preparation of core sands.—J. C. R.

Contribution on the Properties of Bentonite of Braňany (Czechoslovakia). L. Petržela. (Hutnické Listy, 1948, vol. 3, Nov., pp. 335–339). [In Czech]. The properties of synthetic sands produced with bentonite from Braňany are described and compared with those of the French bentonite Clarosol FN. The author also studied the relation between the swelling capacity of bentonite and its mechanical properties and concludes that there is no direct relation between the two : conclusions on the mechanical properties of moulding sand should not be drawn from results of swelling tests alone. E. G.

Resins for Foundries. A. Ambrosioni. (Materie Plastiche, 1947, vol. 13, May–June, pp. 53–54 : [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 9, p. 1984). The physical properties of cores bonded with raw linseed oil and with a special resin are compared. In the latter case the cores have very great strength.

Casting and Pattern Design. J. Hagen. (Neue Giesserei, 1949, vol. 36, Jan., pp. 14–19). Recommendations are made on pattern design for complicated castings, with special reference to methods of preventing hardness on surfaces to be machined, cracks, porosity, and boiling metal in the mould. Examples are described and drawings presented to show improvements to pump and cylinder castings which were made to eliminate the above difficulties.—R. A. R.

Application of Hydraulic Calculations to the Design of Pouring Gates for Castings. J. Kieswetter. (Engineers' Digest (London) 1949, vol. 10, Feb., pp. 47–50). This is an abridged translation of a paper in Czech which appeared in Hutnické Listy, 1948, vol. 3, No. 6, pp. 165–170. (*See* Journ. I. and S.I., 1948, vol. 160, Sept., p. 106).—R. F. F.

Core Binders, Their Nature, Application, and Control. W. W. Magers. (Neue Giesserei, 1949, vol. 36, Jan., pp. 10–13). The properties of core oils, core emulsions, and dry and wet binders are reviewed.—R. A. R.

The Classification of Core Binders and Assessing Them with the Microscope. F. Roll. (Die Technik, 1948, vol. 3, Nov., pp. 478–482). The properties of core binders are reviewed and micrographs of core mixtures are presented to show how these can be worked up in the foundry to produce the desired characteristics. The German classification scheme of 1942 is studied and a new system is recommended.—R. A. R.

Electronic Core Drying. (British Steel Founders' Association Log, 1949, Jan., pp. 8–11). High-frequency dielectric loss heating and its application to core drying is discussed briefly and the layout of equipment with a power input of about 45 kW. and a power output of 25 kW. at 20 to 27 megacycles/sec. is described. Data on costs are presented. An installation of the above type, having a capacity of about 15 cwt. of cores per hr., costs about £100/kW. of high-frequency generator output.—R. A. R.

Foundry Drying Systems. J. B. Morton. (Institute of British Foundrymen: Foundry Trade Journal, 1948, vol. 85, Dec. 30, pp. 619–626; 1949, vol. 86, Jan. 6, pp. 3–8). An illustrated account is presented of various foundry drying systems. Descriptions are given of static and rotary sand driers, and of firing systems, the auxiliary forced-draught, the forced-draught recirculation, and the dry producer systems. Reference is made to the control of drying with batch type ovens or continuous drying stoves. In the second part equipment for drying large cores and moulds is described. This includes bogie- and car-type stoves, pit or underground stoves, portable fire-boxes for pit moulds, and skin or hand-torch drying.—J. C. R.

Grey Cast Iron. Mechanism of Solidification in Hypoeutectic Grey Cast Irons. H. Laplanche. (Fonderie, 1948, Aug., pp. 1253–1270; Sept., pp. 1299–1315). The author first notes the influence of graphite on the mechanical properties of grey cast irons, the influence of silicon on the iron–carbon diagram and the importance of the carbon saturation index, and then describes his investigations on the solidification mechanism in hypoeutectic iron–carbon–silicon alloys. When such an alloy was remelted in nitrogen and allowed to solidify, a primary dendritic structure of austenite was first observed, followed by a eutectic structure. Graphite was noted only in the interior of parts already solidified and no trace was seen in the molten iron. The influence of manganese, phosphorus, and sulphur added singly and together to pure iron–carbon–silicon alloys was noted.

Other points discussed by the author include factors determining the morphology of graphite in ordinary hypo-eutectic irons, methods of causing supercooling, and inoculation of cast irons. The following conclusions are reached: (1) The eutectic of cast irons is of the cellular type and grows radially from the centres of eutectic crystallization; (2) sulphur-free alloys can be supercooled and a ferrite and graphite particle structure is obtained; (3) when supercooling can be carried further, grey irons rich in cementite, then mottled irons, then completely white irons are obtained; (4) when supercooling does not take place a pearlitic or pearlitic-ferritic iron with lamellar graphite, is obtained; (5) supercooling can be prevented by inoculation; and (6) when the graphite is lamellar, with or without inoculations, its average dimensions are determined by the average speed of cooling and the carbon saturation index.—J. C. R.

Defects in Semi-Hardened Cast-Iron Rolls. W. Klimczyk. (Hutnik, 1948, vol. 15, July–Aug., pp. 304–321). [In Polish]. Extensive research has been carried out in connection with defects in semi-hardened cast-iron rolls. Many micro-photographs are shown with the results of the author's own casting experiments.—W. J. W.

The Role of the Metallurgist in the Foundry. T. Watson. (Institute of Australian Foundrymen: Australasian Engineer, 1948, Nov. 8, pp. 97–117). This is a review of the various ways in which the metallurgist is of service in the foundry. It covers the casting of test bars; control of sand, metal charges, and temperatures; and all non-destructive methods of testing.—R. A. R.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Heat-Treatment in a Magnetic Field. J. F. Kayser. (Metal Treatment and Drop Forging, 1948–49, vol. 15, Winter Issue, pp. 193–194). The literature on heat-treatment in a magnetic field is reviewed. It is generally agreed that ferromagnetic substances in the unmagnetized state consist of a conglomerate of domains, spontaneously magnetized close to saturation. There are eight references.—R. A. R.

Controlled-Atmosphere Electric Furnaces: Their Present State and Application. C. E. Peck. (Westinghouse Engineer, 1948, vol. 8, No. 6, pp. 163–166: Chemical Abstracts, 1949, vol. 43, Jan. 10, col. 45). Four general types of atmosphere are commonly used: Endogas (reacted fuel gas), Exogas (combusted fuel gas), Monogas (Exogas with CO_2 and water vapour removed), and Ammogas (cracked anhydrous NH_3). Endogas is used for bright annealing and for carburizing. The electric furnaces are of the Nichrome resistor type. Details as to operation are included.

Steel Treatment without Decarburization in Controlled Atmospheres. H. E. Lewis. (Western Machinery and Steel World, 1947, vol. 36, Oct., pp. 94–99: [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 9, p. 1986).

Gas Generators for Controlled Atmospheres. W. H. Holcroft and M. R. Larson. (Steel, 1949, vol. 124, Jan. 24, pp. 54–55). Generators for controlled atmospheres are described together with their suitability for various heat-treating processes.—J. P. S.

Prepared Atmospheres for the Heat-Treatment of Steel. B. Holman. (Hutnické Listy, 1948, vol. 3, Nov., pp. 339–342; Dec., pp. 362–365). [In Czech]. Physicochemical principles on the control of prepared atmospheres are outlined and a review of the current types of prepared atmosphere is given. Oxidation of steel in furnaces is not due to the influence of CO_2 alone or H_2O alone. The author shows that Heiligenstädt's curve for the CO_2/CO rate in equilibrium with the carbon content of hypoeutectoid steels runs smoothly into Holcroft's curve for steels higher in carbon. Comparison of data given by Heiligenstädt and Holcroft on carburization of steel in atmospheres high in hydrogen with those of Heyn shows that the influence of hydrogen on the carburization effect of the atmosphere is only very slight. A formula is given for calculating the specific consumption of the prepared atmosphere during the cementation process; this equation is valid only for the case when no further hydrocarbons are admitted to the furnace atmosphere during the cementation process.—E. G.

Predicting Carbon Penetration Curves in Carburizing. A. G. Guy. (Iron Age, 1949, vol. 163, Jan. 27, pp. 74–76). Formulæ are derived for determining the penetration of carbon into curved surfaces which take into account the time, the carbon content, the activity coefficient at the given temperature, and the curvature of the part.—J. P. S.

High-Temperature Electrode Salt Baths. G. B. Lamb. (Overseas Engineer, 1948, vol. 22, Jan., pp. 208–210). A detailed description is given of a salt-bath furnace, heated by immersed electrodes, and the operating procedure for heat-treating hot-die steels and high-speed steels using the salt Carboneutral.—R. A. R.

Surface Treatment of Tool Steels. J. Jacquet. (Bulletin Technique Veritas, 1948, vol. 30, Mar., pp. 49–53: [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 9, p. 1987). The following surface treatments are discussed: Cementation (using a carburizing gas, solid or liquid), cyaniding, nitriding (using ammonia gas or a liquid bath), hard chromizing, flame-hardening, and induction hardening. Results of tests on the surfaces obtained are given.

The Hardening of Carbon Tool Steels. C. Chaussin. (Métallurgie, 1949, vol. 81, Feb., pp. 17–19). The author begins by studying the mechanism of hardening and notes the transformations in steel that take place during heating and rapid cooling. He then considers quenching temperatures for hypoeutectoid and hypereutectoid steels, heating prior to quenching including the necessity for avoiding surface oxidation and overheating, cooling during quenching, and subsequent annealing.—J. C. R.

Induction Heating. H. B. Osborn, jun. (Machinery, 1949, vol. 74, Feb. 17, pp. 213–214). The author discusses the rotary converters with frequencies of up to 10,000 cycles, used for induction heating and the theoretical application of induction heating to case-hardening steel.—R. F. F.

Some Economic Aspects of Radio-Frequency Heating. L. M. Duryee. (Transactions of the American Institute of Electrical Engineers, 1948, vol. 67, Part I, pp. 105–112). Factors

influencing the selection and cost of high-frequency induction heating are discussed and formulæ are developed for determining the most economic frequency for various applications, one example being heating the ends of bolts for the heading operation.—R. A. R.

High-Frequency Heating—Its Fundamentals and Technical Applications. K. Kegel. (Zeitschrift des Vereines deutscher Ingenieure, 1949, vol. 91, Jan. 15, pp. 25–32). Having explained the principles of high-frequency heating and described high-frequency generating equipment, examples of heating coils and devices for the continuous production of small parts are shown. Dielectric heating and its applications are also discussed.—R. A. R.

Bright Annealing Saves Money. (Ceramic Industry, 1948, vol. 50, No. 6, p. 100 : American Ceramic Abstracts, 1948, Nov. 1, p. 239). As a method of cleaning metal, bright-annealing is being used successfully to replace pickling. Furnaces are electrically heated and metal is cleaned at 1500° F. to 1600° F. The operation takes less space than pickling and costs less.

FORGING, STAMPING, DRAWING, AND PRESSING

A Review of the Application and Design of Heavy Forging Presses. J. A. Sanderson and J. G. Frith. (Journal of The Iron and Steel Institute, 1949, vol. 161, Mar., pp. 231–246). The paper describes present-day forging practice, with the tendency towards larger ingot sizes, and the probable press powers which will be required to deal with these ingots. Details of the size and location of existing heavy presses are given, together with lists of the ingot capacities of the various sizes both for forging and upsetting, and British and American practice in these respects are compared. Various methods of press construction, particularly as regards the guiding of the crosshead, are considered, and the influence of these methods upon the number of main cylinders and upon the choice of press drive is discussed. The steam-hydraulic, direct pump and air/hydraulic-accumulator types of press drive are described with particulars of the sizes of pumps used, and a 12,000-ton press supplied to the U.S.S.R. in 1939 is selected for the consideration of detailed features of design.

Calculating the Capacity of Forging Presses and Hammers. M. Zscheile. (Österreichischer Maschinenmarkt und Elektrowirtschaft, 1948, vol. 3, Dec. 31, pp. 402–404). Examples of calculations are presented to show how the capacities of forging presses and hammers can be determined without requiring any expensive instruments from dimensional changes when pressing lead cylinders.—R. A. R.

Data for Determining the Initial Amount of Material for Forgings. P. Patek. (Betrieb und Fertigung, 1949, vol. 3, Feb., pp. 21–24). This paper deals with the calculation of the size of the raw material required to make a die-forging of given finished dimensions, in particular, the allowances which have to be made for machining, contraction, scale losses, and flash.—R. A. R.

The Manufacture of High Speed Tool Steel. G. A. Burrell. (Australian Institute of Metals : Australasian Engineer, 1948, Nov. 8, pp. 61–68). The effects of tungsten in steel, and the constitutional diagram of the iron–carbon–tungsten system are briefly examined. The types, advantages, and disadvantages of various mechanical means of reducing high-speed steel ingots, particularly the forging, are dealt with at length, whilst, in conclusion, the heat-treatment and applications of modern high-speed steel are discussed.

Forging Die Design.—The Bender. J. Mueller. (Steel Processing, 1948, vol. 34, Oct., pp. 527–529 ; Dec., pp. 641–643, 648). The use of a ' bender ' in multi-impression forging dies is explained and examples are given of its use in the manufacture of crankshafts, door handles, gear-changing yokes, anchor shackles, spring clips, hose clamps for pneumatic brakes, and railway towing hooks.—R. A. R.

Upset Forgings. H. A. Whiteley. (Metal Treatment and Drop Forging, 1948–49, vol. 15, Winter Issue, pp. 195–202). A comprehensive and illustrated account is given of the production of upset forgings. The effects of forging on the structure and properties, the steels used for dies and tools, heating furnaces, piercing operations, inspection and tolerances, heat-treatment, and production by a combination of upset and drop forging are dealt with.—R. A. R.

The Manufacture of Wrought Steel Wheels. W. A. Ashton and R. N. Merk. (Iron and Steel Engineer, 1948, vol. 25, Dec., pp. 37–48). After reviewing the history and developments in the production of wheels, the authors outline present-day practice in the manufacture of wrought steel wheels at the works of the Carnegie-Illinois Steel Corporation. The various processes are described and illustrated. A plan shows the layout of the wheel and axle plant at the Homestead District Works of the Carnegie-Illinois Steel Corporation. J. C. R.

The Production of Bright Steel Bars. (Machinery, 1949, vol. 74, Jan. 6, pp. 3–9). The plant and methods employed by the Exors. of Jas. Mills, Ltd. are described. The mechanical properties of various steels, known as Mills Ledloy Steels, are compared with standard steels. Two of the five rolling mills at the works are described ; one is a 10-in. mill rolling small bars into 100-ft. lengths, the other an 18-in. mill rolling bars 60 ft. long. The recently installed new pickling plant, together with the handling equipment, and the bar turning, bar grinding machines, bar straightening presses, and draw benches are described in detail.—R. F. F.

Wire-Drawing with Continuous Drawing Machines. S. Geleji. (Wire Industry, 1949, vol. 16, Jan., pp. 53–56). Formulæ are developed for calculating the power requirements of slip and non-slip continuous wire-drawing machines. R. A. R.

ROLLING-MILL PRACTICE

The Calculation of the Power Requirements of Rolling Mills. S. Geleji. (Bányászati és Kohászati Lapok, 1948, vol. 3, Dec. 15, pp. 315–318). [In Hungarian]. Formulæ are derived for calculating the power required in rolling mills when rolling square, oval, and round sections. The formulæ given in this paper are based on an equation developed in a previous paper by the author (*see* Journ. I. and S.I., 1948, vol. 160, Oct., p. 225). The values obtained by calculation were in good agreement with results obtained experimentally in a case which is cited.—E. G.

Power for an Industrial Plant. Steam. E. M. Yard. **Electric Power.** W. E. Zelley. (Iron and Steel Engineer, 1948, vol. 25, Dec., pp. 75–84). The authors discuss factors governing the choice of steam and electricity generating equipment for rolling mills and other steelworks plant.—J. C. R.

A Four Channel Instrument for the Measurement of Torque and Roll Force in the Steel Industry. A. L. M. Douglas and P. R. A. Briggs. (Instrument Practice, 1948, vol. 3, Dec., pp. 65–71). Equipment designed for the continuous measurement and recording of the torque in each spindle and the roll force under each screw in industrial rolling mills is described. Resistance strain gauges form the measuring elements and these are arranged to form a Wheatstone bridge. Loads up to 100 tons have been measured with an accuracy of 1%, and torques of the order of 100 ft.lb. upwards with an accuracy of 3%. The same circuit could be used to measure the stresses in any structure subject to deformation.—R. A. R.

Electric Equipment for Cold Strip Reduction Mills. W. E. Miller. (Transactions of the American Institute of Electrical Engineers, 1948, vol. 67, Part I, pp. 133–140). *See* Journ. I. and S.I., 1949, vol. 161, Feb., p. 154.

Improvements in Rolling Mill Preset Screw-Down Controllers. J. D. Leitch and C. A. Schurr. (Transactions of the American Institute of Electrical Engineers, 1948, vol. 67, Part I, pp. 58–63). A screwdown controller incorporating electronic-balance detectors and anticipators is described. It permits high screwdown motor speeds without loss of accuracy in the final positioning of the rolls. A new system of schedule panels on which one or more complete rolling programmes can be present is a feature of this equipment.—R. A. R.

The Development of Screwdowns for Sheet Mills. W. Kramer. (Stahl und Eisen, 1949, vol. 69, Feb. 3, pp. 86–93). Several new designs of screwdown for cold and for hot sheet-mill stands are described and illustrated. These show that many of the difficulties involved have been overcome.—R. A. R.

The Calculation of Mean Reduction in Pass Rolling. I. Ya. Tarnovskiy. (Iron and Steel Institute, 1949, Translation Series, No. 372). This is an English translation of a paper which appeared in *Stal*, 1948, No. 3, pp. 232–240. (*See* Journ. I. and S.I., 1948, vol. 159, July, p. 334).

The Use of Wooden and Synthetic-Resin Bearings in Rolling Mills. M. Quillatre. (Iron and Steel Institute, 1948, Translation Series, No. 356). This is an English Translation of a

paper which appeared in Revue de Métallurgie, Mémoires, 1941, vol. 38, Oct., pp. 253–271 ; Nov., pp. 285–298. (*See* Journ. I. and S.I., 1948, vol. 158, Mar., p. 400).

Republic's 44–36–32 in. Mills at Chicago. R. F. Lavette. (Iron and Steel Engineer, 1948, vol. 25, Oct., pp. 37–41). The plant described comprises a 44-in. reversing blooming mill, a 36-in. two-high roughing mill, and a 32-in. mill consisting of three two-high finishing stands. The plant was built in 1943–1944 for the production of electric-furnace alloy steels used in the manufacture of aircraft, guns, tanks, etc. A feature of the plant is the unusually large and deep soaking pits which consist of 24 cells of one-way-fired recuperative pits, each cell being 25 ft. × 8½ ft. × 15½ ft. deep.—J. C. R.

The Appleby Rolling Mills. J. Dodd. (Lincolnshire Iron and Steel Institute, Jan. 25, 1949 : Iron and Coal Trades Review, 1949, vol. 158, Feb. 4, pp. 235–238). An account is given of the rolling mill plant of the Appleby-Frodingham Steel Co., Ltd. which consists of a 42-in. slabbing mill and two plate mills. The slabbing mill is a 42-in. two-high reversing mill which rolls ingots into slabs for the plate mills and also rolls a small quantity of slabs and forging blooms for sale. The 10-ft. plate mill is a 42-in. two-stand side-by-side two-high reversing mill, and the 7-ft. plate mill is a two-stand tandem, the first stand being two-high.—J. C. R.

X-Ray Thickness Gauge for Cold Rolled Strip Steel. W. N. Lundahl. (Transactions of the American Institute of Electrical Engineers, 1948, vol. 67, Part I, pp. 83–90) *See* Journ. I. and S.I., 1948, vol. 159, Aug., p. 451.

An X-Ray Thickness Gauge for Hot-Strip Rolling Mills. C. W. Clapp and R. V. Pohl. (Transactions of the American Institute of Electrical Engineers, 1948, vol. 67, Part I, pp. 620–626). *See* Journ. I. and S.I., 1948, vol. 160, Nov., p. 335.

MACHINERY FOR IRON AND STEEL PLANT

Electric Control of Industrial Drives. (Power Transmission, 1948, vol. 17, Oct. 15, pp. 1053–1054 : [Abstract] PERA Bulletin, 1949, vol. 2, Jan., p. 50). Developments in electric control gear in the machine tool and steel industries are briefly discussed.

Excess Heating of Electric Motors. J. L. Watts. (Iron and Coal Trades Review, 1949, vol. 158, Jan. 28, pp. 179–183). This is a review of the causes of overheating of electric motors, their remedies and precautions that can be taken. It is applicable to electric motors in use in steelworks. Amongst the factors discussed are motor starting and protection, the effects of overloading, and overheating caused by broken winding connections, faulty operation of starters, and other mechanical faults.—J. C. R.

Dynamic Braking Magnetic Hoist Controller. K. S. Kuka. (Iron and Steel Engineer, 1948, vol. 25, Dec., pp. 89–94). A description is given of a dynamic braking magnetic hoist controller for use with overhead steelworks cranes.—J. C. R.

Crane Block, Limit Switch and Hoist Cable Failures. F. W. Cramer. (Iron and Steel Engineer, 1948, vol. 25, Dec., pp. 95–101). An account is given of the operation of limit switches and hoist brakes on electric overhead travelling cranes. The prevention of hoist cable failures is discussed.—J. C. R.

Description of New Plant.—Automatic Loading Controller. (Journal of The Iron and Steel Institute, 1949, vol. 161, Jan., pp. 45–46) Wagons taking pig iron from a 2-strand pig-casting machine are frequently overloaded and this has led to a demand for a counting and weight-indicating apparatus for continuous loading operations. Such a loading controller is described. It has a feed switch actuated by each unit of load entering the wagon, in this case two pigs, a uni-selector device which is stepped forward by feed-switch actuations, and an indicator device which shows when a predetermined full load has entered. It can be arranged to indicate when a predetermined fraction of the full load has been reached, thus enabling, for example, the position of the wagon to be changed when half loaded so as to secure uniform distribution.
R. A. R.

LUBRICANTS AND LUBRICATION

A Worker-Consistometer for Lubricating Greases. S. A. McKee and H. S. White. (A.S.T.M. Bulletin, 1948, Aug., pp. 90–98). An apparatus is described for mechanically working a lubricating grease and measuring its flow characteristics in the same series of operations. It consists essentially of two coaxial steel cylinders with a capillary-type shearing element located between them. By means of closely fitting pistons the grease under test is forced through the shearing element from one cylinder to the other. In making flow measurements dead weights are used on the down stroke, and air pressure on the upstroke. Provision is also made for automatic mechanical working. Test data are given showing the effect of working upon the flow characteristics of greases. Data are also given which indicate that with some greases changes in the rate of working affect the flow characteristics of the grease. Comparative data are given for this worker and the A.S.T.M. worker. The chief advantages of this apparatus are that grease may be worked and its flow characteristics measured in the same series of operations, and that a complete series of tests may be made while the grease is held at a constant temperature.—J. C. R.

Application of Colloidal Graphite to Some Lubrication Problems. A. H. Stuart. (Scientific Lubrication, 1948, vol. 1, Oct., p. 15 : [Abstract] Journal of the British Shipbuilding Research Association, 1948, vol. 3, Dec., pp. 561–562). The function of the lubricant in fluid-film lubrication is explained. Although many lubricating oils will fulfil these functions satisfactorily under normal running conditions, they are likely to fail when conditions become bad. The result is metal-to-metal contact of the bearing surfaces, leading, under heavy loads, to a cold weld. Pure, artificially produced graphite, which can be produced in colloidal suspensions, forms a film of graphite on the surface of the bearing in which the planes of cleavage of the graphite are parallel to the surface. The graphite is held to the surface by adsorption, and is unaffected by temperature or pressure ; it can only be dislodged by direct abrasion. The marked ability of graphite to absorb gases and vapours, especially water vapour, contributes to its power of lubrication. Where it is undesirable for oil lubrication to be used a dry lubricating film can be formed by brushing or spraying a colloidal solution of graphite in a suitable medium over the surface and allowing the film to dry. In rolling mills where bearings of resin-bonded fabric are often used, the best results can be obtained by depositing a film of colloidal graphite on the surface and using a 1% solution of sodium oleate as a coolant.

Grease Lubrication—Properties and Applications of Greases. A. Boecker. (Zeitschrift des Vereines deutscher Ingenieure, 1948, vol. 90, Dec., pp. 366–368). The production and properties of lubricating greases are reviewed with notes on the requirements of greases for pressure-fed systems, very high pressure applications, water pumps, hot bearings, gear wheels, and cold and hot rolling-mill bearings.—R. A. R.

WELDING AND FLAME-CUTTING

Research and Development in the U.S.A. and Canada. H. G. Taylor. (Welding, 1948, vol. 16, Dec., pp. 504–510). The author reports some of the important developments in welding science he observed during a recent tour in the U.S.A. and Canada. In the field of resistance welding, various types of equipment have been devised to reduce the peak demand on mains and to equalize the demand from the three phases ; the principles of some of these types are described. Gas pressure welding for tube and bar ends is described. Intensive research with very high speed photography is being conducted on the physics of the arc ; it has been shown that a short circuit can take place in the interval between the exposure of two consecutive frames of a film taken at 300 exposures/sec.—R. A. R.

Influence of the Wall Thickness on the Weldability of Steel. J. Verö. (Bányászati és Kohászati Lapok, 1948, vol. 3, Nov. 15, pp. 277–287). [In Hungarian]. The influence of the wall thickness on the cooling rate of welded steel parts is analysed and theoretical conclusions are compared with results obtained experimentally. The temperature distribution round a point of heat input is given by the J_0 Bessel function for thin sheets, and by the (sine x)/x function for thick plates. The isotherms have a cylindrical shape for thin sheets, whilst for thick plates they are spherical. The structural changes of the base metal permit the determination of the maximum temperatures reached during the welding process at various points, and the values obtained enable the maximum temperature characteristic of the cross-section affected by the welding to be plotted. The places where the A_3 and A_1 temperatures were reached can be recognized and their distance from the

parent-metal/weld-metal line can be measured. The curve for maximum temperature plotted against this distance is flattest for 7-mm. sheets whilst it gets steeper for thinner as well as for thicker sheets. These curves permit calculation of the initial cooling speeds as a function of the wall thickness, and this speed is lowest for 7-mm. sheets. The influence of the cooling speed on the hardness was also determined experimentally for several types of steel, and, by comparison with the maximum hardness after welding, it was possible to determine the cooling speeds in the welds concerned. These experimental results confirmed the theoretically derived conclusions on the influence of the wall thickness. To produce satisfactory welds in thicker sheets or sheets made of harder steel, it is advisable to apply large heat inputs and to increase the welding speed as much as possible.—E. G.

The Equilibrium between Liquid Silica and Liquid Iron. J. D. Fast. (Philips Research Reports, 1948, vol. 3, pp. 271–280 : Chemical Abstracts, 1949, vol. 43, Jan. 10, col. 23). The equilibrium between liquid silica and liquid iron is of importance in arc welding because welding-rod coatings usually contain much silica. Compositions of the metal and slag phases when liquid iron is in equilibrium with liquid silica at 2000° K. are computed. For silica : iron mole ratios of $\frac{1}{10}$, $\frac{1}{5}$, $\frac{1}{3}$, and $\frac{1}{2}$, the weight percentages of silicon in the metal are 0·12, 0·15, 0·20, and 0·28, respectively, those of oxygen in the metal are 0·083, 0·074, 0·064, and 0·054 respectively, and the mole percentages of FeO in the slag are 2·89, 2·59, 2·24, and 1·87 respectively.

The Combined Use of Casting and Welding in Steel Construction. H. Gerbeaux. (Soudure et Techniques Connexes, 1948, vol. 2, Sept.–Oct., p. 184 : [Abstract] Journal of the British Shipbuilding Research Association, 1949, vol. 4, Jan., pp. 16–17). The author discusses modern British, American, and French techniques in the construction of components consisting partly of steel castings and partly of rolled sections or plating, the two being joined by welding. Gas and arc welding is not only useful as a means of repairing faulty steel castings, but is now also largely employed in joining parts formed from cast and rolled components. This method, if applied correctly, offers amongst many other advantages those of simple and speedy production, reduction of internal stresses, and easy machining. It is a primary condition for the combined application of steel casting and welding that the components from which a machine part is to be made up are of simple shape and not too large, so that they can be cast without danger of the occurrence of high internal stresses and porosity. Welded objects should be annealed properly to remove possible welding stresses. Attention has to be paid to the composition and casting practice of steel and some American rules for the weldability of cast-steel alloys, based on their hardenability and their chemical composition are given. By jointing a casting intelligently to two previously welded rolled components, good results may be obtained where otherwise difficulties would arise in the construction.

Submerged Melt Welding in Steel Mills. E. D. Morris. (Iron and Steel Engineer, 1948, vol. 25, Dec., pp. 85–88). The use of submerged-melt welding in steel mills is of two general types : the fabrication of equipment of various kinds, and the reclaiming of worn surfaces by building-up. Comparative costs were obtained from actual installations and are given in this discussion of the applications of this method of welding.—J. C. R.

A Constitution Diagram Applicable to Stainless Weld Metal. R. D. Thomas, jun. (Schweizerischer Verband für die Materialprüfungen der Technik : Schweizer Archiv, 1949, vol. 15, Jan., pp. 1–22). Tentative constitutional diagrams for chromium-nickel weld metal constructed in the manner described by A. L. Schaeffler (*see* Journ. I. and S.I., 1948, vol. 158, Mar., p. 402, and vol. 160, Nov., p. 326) are presented and the effects of small quantities of columbium and molybdenum on the microstructure, cracking tendency, and formation of the sigma phase are discussed. It is shown how to use the diagrams to predict the composition of weld metal deposited on dissimilar metals.—R. A. R.

Resistance Welding. T. B. Milne. (South African Welder and Machinist, 1948, vol. 1, Nov., pp. 3–11). Recommendations are made on the resistance welding of ferrous and non-ferrous metals with special reference to the material and shape for the electrodes. Among the methods described is the Sciaky or 3-winding 3-phase system ; it involves the passage of current in the same direction through three groups of coils wound on the same core which has a common secondary ; the system produces a low-frequency alternating current in the secondary from a 3-phase normal-frequency supply. R. A. R.

Some Investigations on the Resistance Welding of Sheets. F. Eisenkolb. (Die Technik, 1948, vol. 3, Dec., pp. 521–528). The deformation characteristics of unwelded and butt-welded steel sheets from 0·67 to 1·03 mm. thick were investigated. Slight increases in the carbon and/or sulphur contents of the steel reduced the drawing properties of both autogenous, and electrical resistance weld. Good drawing properties were obtained after annealing the welds at 750° C.—R. A. R.

The Welding of Sheets Considered from the Aspect of the Finished Part. H. von Conrady. (Die Technik, 1948, vol. 3, Dec., pp. 529–532). Examples are given to show the wide variety of objects which can be made from steel sheet up to 3 mm. thick by employing different forms of welded joint. R. A. R.

Oxygen and Acetylene Gas Distributing System. J. S. Gray. (Steel, 1949, vol. 124, Jan. 10, pp. 60–61). A firm in the scrap preparation industry has installed its own oxygen and acetylene producers, and a pipe-line distribution system. Savings in time and money are claimed.—J. P. S.

PROPERTIES AND TESTS

An Investigation of the Stress-Strain Diagram at Low Temperatures. E. M. Shevandin. (Zavodskaya Laboratoriya, 1947, vol. 13, No. 7, pp. 858–870 : [Abridged Translation] Engineer's Digest (London), 1949, vol. 10, Jan., pp. 7–10). Stress over area-reduction diagrams were obtained for various temperatures between + 20° and − 196° C. The metals tested included steels with 0·12%, 0·2%, and 0·4% of carbon. One specimen of each was subjected to normal heat-treatment and another was over-annealed to coarsen the grain. A 5% nickel steel, untreated, and copper annealed at 650 C., were also tested. The results obtained are plotted as curves and discussed.—R. F. F.

Various Tests in Metallurgy. L. Grenet. (Echo des Mines, 1948, Nov., p. 217 ; Dec., p. 238). The author discusses very briefly the purpose of most of the tests used in metallurgy. R. F. F.

Tearing Experiments on Metal Sheets. P. W. Rowe and C. Gurney. (Ministry of Supply, 1948, A.R.C. Technical Report 2282 : [Abstract] Bulletin of the British Non-Ferrous Metals Research Association, 1948, Dec., p. 407). The tearing resistance of a given material, measured by the load needed to tear a tongue from a metal sheet, was found to be proportional to the sheet thickness squared. Of the materials tested, mild steel has the highest tearing resistance, being about six times that of magnesium alloy D.T.D. 118, which had the least tearing resistance.

Distribution of Torsional Deformation along the Length of the Specimen. M. V. Yakutovich and F. P. Rybalko. (Comptes Rendus (Doklady) de l'Académie des Sciences de l'U.R.S.S., 1948, vol. 60, Apr. 11, pp. 227–229 [In Russian] : [Abstract] Bulletin of the British Non-Ferrous Metals Research Association, 1948, Dec., p. 407). Curves showing the distribution are given for a high-duty steel and for brass ; for the steel the maximum shear deformation is seven times the mean.

Bending Tests of Large Welded-Steel Box Girders at Different Temperatures. A. H. Stang and B. S. Jaffe. (Journal of Research of the National Bureau of Standards, 1948, vol. 41, Nov., pp. 483–487). Tests were made to determine the effect of constraint caused by geometrical shape and by differences in temperature on the ductile behaviour of four large box girders of identical design. Bend tests were made at −40°, 0°, 40°, and 80° F. Those tested at −40° and 0° F. broke with a square type of fracture. The other two girders could not be broken with the equipment available although deflections of more than 16 in. were induced on a 22-ft. span. Tensile tests on specimens of the same heat of steel showed equal ductility at all four temperatures.—R. A. R.

Cold-Brittleness of Steel in Compression. D. M. Zagorodskich. (Journal of Technical Physics, U.S.S.R., 1948, vol. 18, June, p. 843 [in Russian] : [Abstract] Journal of the British Shipbuilding Research Association, 1948, vol. 3, Dec., pp. 543–544). Experiments have shown that the presence of internal tensile or thermal stresses in a specimen has no effect on the

critical temperature of brittleness. To investigate the effect of compression, the author has carried out a number of experiments which are described. The impact tests were carried out with Amsler apparatus using unstressed and stressed specimens, the latter being compressed by means of a special spring-loaded device described and illustrated in the paper. The steels used contained 0·09% C, 0·10–0·11% Cr, 0·47–0·48% Mn, 0·046–0·049% S, and 0·025% P. The mechanical properties are tabulated. Liquid oxygen was used as the cooling medium and the specimens were tested at intervals of temperature of 5·4° F. within the range −360° F. to +5° F. The upper critical temperature was considered to be the one at which one of the six specimens tested at the same temperature gave brittle fracture while the lower critical temperature was one at which all six specimens showed brittle fracture. The results showed that for the compressed specimens the upper critical temperature was 54° F. below and the lower critical temperature 94° F. below the corresponding temperature for the unstressed specimens.

The Residual Stresses in Round Bars with Pressed Surfaces. O. Föppl. (Zeitschrift des Vereines deutscher Ingenieure, 1948, vol. 90, Dec., pp. 369–372). Timoshenko has applied Sachs' formula to calculate the distribution of stresses in a round bar the surface of which has been pressed, but the present author finds this method of calculating does not give accurate results. The present paper describes a method of calculation using data obtained from a composite round bar consisting of a non-plastically deformed bar inside a uniformly plastically deformed tube, held together by elastic stresses. Theoretical considerations provide a criterion for determining the thickness of the outer layer which is plastically deformed by the surface pressure. Measurements of dimensional changes in surface-pressed bars which have been drilled out agreed with the theoretically calculated data. The stress distribution in the plastically deformed outer layer at any position in the outer tube can be determined using a series of hyperbolas. The results of this investigation and those of others, particularly Timoschenko, are discussed.—R. A. R.

Residual Stresses in Enameled Sheet-Iron Specimens. R. A. Jones and A. I. Andrews. (Journal of the American Ceramic Society, 1948, vol. 31, Oct. 1, pp. 274–279). A method for measuring the stresses present in porcelain enamelled specimens is explained and described. This method consists of measuring, by means of a mechanical strain gauge, the dimensional changes occurring when the enamel is removed. The theory is discussed and the results obtained with thirty ground coated specimens, are tabulated.—R. F. F.

Plastic Deformation and the Rupture of Metals. P. Laurent and R. Laurent-Lamothe. (Société Française de Métallurgie Oct. 10, 1947: Revue de Métallurgie, Mémoires, 1948, vol. 45, Dec., pp. 515–520). The mechanism of the deformation of single crystals and of the fracture of polycrystals is discussed. A. E. C.

A New Electronic Method for the Measurement of an Electrical Quantity and Its Application to the Indication of Strain, Static and Dynamic. E. H. T. Jackson. (Seventh International Congress of Applied Mechanics, London, Sept. 1948: [Abstract] Journal of the British Shipbuilding Research Association, 1948, vol. 3, Oct., p. 465). The method described depends on voltage change only and can be used to measure any physical quantity which can be transformed into a potential difference. For example, the resistance change of an electrical strain gauge when strained is transformed into a potential difference by a split bridge circuit developed for the instrument in question. The experimental model of a static strain tester of this type gives a sensitivity of 1 part in 100,000 of strain. It is hoped to extend the use of the system to the measurement of dynamic strain.

Why Peening Calls for Uniform Shot. J. Straub. (SAE Journal, 1948, vol. 56, Nov., pp. 37–38). Shot-peening tests are described which proved that peening with shot containing a high percentage of broken particles is much less beneficial to the fatigue strength of the part than peening with whole shot. The shot should not only be unbroken but should be of uniform size.—R. A. R.

Effect of Shot Type on Spring Fatigue Life. F. P. Zimmerli. (SAE Journal, 1948, vol. 56, Nov., pp. 36, 39). *See* Journ. I. and S.I., 1949, vol. 161, Jan., p. 72.

Shot Peening and Fatigue Failure. R. A. Nairn. (Commonwealth Engineer, 1947, vol. 35, Aug. 1, pp. 10–18).

Shot Peening for Longer Life. L. J. Wieschhaus. (Modern Machine Shop, 1948, vol. 21, Sept., pp. 112–114, 116, 118, 120, 122, 124, 126, 128, 130: [Abstract] PERA Bulletin, 1948, vol. 1, Dec., pp. 834–835). The author shows how the action of the shot during the shot-peening process sets up compressive stresses in the skin of a component and so increases its resistance to tensile fatigue. Shot-peening can also be used to inhibit stress corrosion cracking or to reduce leakage caused by porosity. The strengthening properties of shot-peening offer opportunities for reducing the weight of components or introducing cheaper material into a product. The shot may be directed on to the work by air or by a Wheelabrator. Various methods are suggested for moving different components under the shot spray to ensure optimum results. It is important to keep the blasting intensity consistent, and in order to check this, a special gauge and method have been developed whereby the curvature induced by peening of standard metal test strips is used as a measure of the peening intensity.

Selective Shot Peening Extends Fatigue Life. J. Epprecht and H. W. Eberhardt. (Machinist, 1949, vol. 92, Feb. 5, pp. 1315–1318). Methods used by the Curtiss-Wright Propeller Division, for the shot-peening of highly stressed areas of critical parts are described. The shot used are the Pittsburgh Crushed Steel Co. P.28, which have a hardness of 55 Rockwell C. The parts treated include gears, spiral-bevel blades, and power gears of propeller hubs.—R. F. F.

The Fatigue Test under Increasing Load. A New Technique for Testing Materials. E. M. Prot. (Société Française de Métallurgie, Oct. 10, 1947: Revue de Métallurgie, Mémoires, 1948, vol. 45, Dec., pp. 481–489). After pointing out the long time required for conventional fatigue or endurance tests and the scatter of the results obtained and touching on attempts to accelerate them, the author advocates the use of a test in which the load, and hence the stress, on the specimen are increased progressively with time. An advantage is that sooner or later the specimen breaks so that the results all relate to a single condition (specimen broken), not to two, as is more usual when some of the test-pieces break and some do not. The simplest procedure would be to make a series of tests with loads increasing more and more slowly, and plotting the load at fracture against the number of cycles required to fracture. Under rapid loading, the specimen would not be sufficiently fatigued under low stresses near the fatigue limit, and would break under a higher stress near the elastic limit in a relatively short time; under a slowly rising stress, fracture would occur much later under a stress not very much above the fatigue limit and which would approach more closely to the fatigue limit as the rate of stress increase diminished. Again, the stress at fracture might be plotted against the rate of increase of stress or, better, the square root of this increase (provided that it was linear): the fatigue limit would be given by the point of contact of the curve with the ordinate axis. After discussing the theory of the new test method the author describes an apparatus using a rotating cantilever specimen the load on which is increased by the addition of 10-g. steel balls to the loading pan at regular intervals.—A. E. C.

Coil Springs—Excess Stress. R. Saxton. (Power Transmission, 1948, vol. 17, Oct. 15, pp. 1012–1013: [Abstract] PERA Bulletin, 1949, vol. 2, Jan., p. 52). Various cases of fracture in heat-treated springs, including acid and hydrogen embrittlement, are briefly discussed.

Spring Design and Manufacture. J. A. Roberts. (Engineering Inspection, 1948, vol. 12, Winter Issue, pp. 25–35). *See* Journ. I. and S.I., 1948, vol. 159, June, p. 231.

A New Micro-Hardness Tester. P. Ramsthaler. (Microtecnic, 1948, vol. 11, Oct., pp. 207–211). A new microhardness tester, which is an improvement on the Hanemann-Zeiss instrument, is described in detail. In the new instrument the same optical system may be used for observation and for measurement of impression. Suitable mechanical devices enable the diamond pyramid indenter and the objective to be interchanged in less than a second.—R. A. R.

Use of Hardness Data Restricted. A. R. Troiano. (Steel, 1949, vol. 124, Jan. 17, pp. 66–71). The author has compared three steels of similar Jominy hardenability, SAE 5140 (C 0·41%, Mn 0·90%, Si 0·27%, Cr 1·04%, Ni 0·04%); SAE 2340 (C 0·40%, Mn 0·89%, Si 0·31%, Cr 0·11%, Ni 3·34%); SAE T1340 (C 0·40%, Mn 2·06%, Si 0·40%, Cr 0·11%, Ni 0·05%), determining their transformation

diagrams, and studying the retention of austenite by X-ray diffraction. He has found that, whereas in SAE 5140, the pearlite and bainite reactions are separated with respect to time but overlap with respect to temperature at 1100° F. (590° C.), in steel SAE 2340, these reactions overlap in the range 800°–960° F. (425°–515° C.) both in time and temperature; in the case of SAE T1340, the reactions overlap in time and temperature in the range 1030°–940° F. (545°–505° C.), but are separated below 940° F. (505° C.) and this steel thus occupies an intermediate position. Study of retained austenite in the Jominy bars confirms this, SAE 5140 showing a greater degree of decomposition of austenite to bainite, ferrite, etc., than SAE T1340, and this in turn more than SAE 2340; the mechanism of transformation is similar in all three cases. These phenomena are connected with the fact that the higher the temperature at which retained austenite is tempered, the greater is the stabilization on subsequent cooling. The author concludes that the Jominy curve is limited as a tool for comparison of steels even of comparable hardenabilities, since hardness data do not reveal all the possible variations in structure.—J. P. S.

Hardenability and Weldability of Steels. H. Granjon. (Soudure et Techniques Connexes, 1947, vol. 1, Nov.–Dec., pp. 230–242: [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 9, p. 1991). Methods for the determination of hardenability and weldability are considered. Microexaminations and hardness tests enable hardenability to be studied. Reference is made to the use of **S**-curves and Jominy tests.

Age-Hardening of Ingot Iron. Influence of Short-Time Heat Treatment. W. J. Geller and H. Kuntze. (Iron and Coal Trades Review, 1949, vol. 158, Jan. 28, pp. 173–176). Two different sheets (0·059 in. thick) of ingot iron (C 0·043%, Mn 0·16%, Si trace, P 0·021%, S 0·030%, and N 0·003%; and C 0·040%, Mn 0·16%, Si trace, P 0·023%, sulphur and nitrogen not determined) were used for the experimental work. Solution heat-treatment was carried out for 30 min. at 690° ± 10° C. in a salt bath and all other heat-treatments either in a salt or oil bath. Each treatment was followed by quenching in water at 15° C. Details are given of experiments carried out to investigate the influence of a short-time heat-treatment after one or two weeks of age-hardening at room temperature. Results show that a reversion of age-hardening can be obtained by an appropriate heat-treatment. The stability of the age-hardened condition against the re-formation treatment increases with prolonged age-hardening at room temperature or hardening at elevated temperatures. The phenomenon is explained as a continuous process of nucleation and growth from the first gathering of carbon atoms in the α-iron lattice to the precipitation of the carbide and its final equilibrium with the α-iron. In the early stages of this process it can be reversed by a short-term heat-treatment which becomes increasingly difficult with the progress of this process.—J. C. R.

Ageing of Steel. B. D. Enlund. (Jernkontorets Annaler, 1949, vol. 133, No. 1, pp. 1–28). [In Swedish]. Low carbon steels will often show a considerable embrittlement on ageing at room temperature or at different elevated temperatures if they are previously cold-worked. If the steel is transformed into a sufficiently fine-grained condition no embrittlement will occur. The grain refinement may be attained by means of an addition of aluminium during pouring and a normalizing treatment at about 930° C. after rolling. Still better results are obtained if the steel is quenched from 950° C. and subsequently tempered at 600° to 650° C. for half an hour. The latter method is especially suitable for finished articles, and may be applied to steel with or without aluminium. It was found that a cold-worked as well as an aged material may be restored to a tough condition by tempering at 600° to 650° C.°

No explanation is given of the increase in hardness on ageing after cold-working, but the brittleness which is of practical importance was found to be definitely related to the grain size.—J. K.

Alloying White Cast Iron Increases Abrasion Resistance. K. A. DeLonge. (Engineering and Mining Journal, 1948, vol. 149, Oct., pp. 86–89). The addition of 4·5% of nickel and 2% of chromium to white cast iron changes the matrix from the usual pearlitic to the hard martensitic structure; it also hardens and refines the carbides. Martensitic white iron has a hardness range of 550–725 Brinell and high hardness is maintained throughout sections 4 to 6 in. thick. The abrasion resistance can be further increased by chill casting. The residual austenite in the martensite work-hardens at the wearing surface. The properties of pearlitic and martensitic sand-cast and chill-cast white irons are given in tables together with a comparison of the service lives of grinding balls and liners for ore-grinding machinery.—R. A. R.

The Abrasion Resistance of Metals R. D. Haworth, jun. (American Society for Metals, Oct. 1948, Preprint No. 42). An illustrated description is given of a new laboratory abrasion-testing device which is a modification of the Brinell abrasion machine, having a larger, thicker rubber (instead of steel) wheel. With this machine it is possible to determine the resistance of metals to dry and wet abrasion. Weight-loss values obtained under several abrasive conditions are presented for a variety of metallic materials. Results indicate that, in the absence of impact, carbon is the most effective alloying element in producing resistance to abrasion. With the same abrading material, dry abrasion is usually more severe than wet abrasion. The degree of angularity of the abrading material has a marked effect on the extent of abrasive wear produced. Ordinary methods of hardness determination show no reliable correlation with abrasion resistance. Hardness of the microconstituents relative to the abrading material together with the size, distribution, and quantity of the hard phases in the structure appear to be determining factors in abrasion resistance. Such special surface treatments as carburizing, nitriding, siliconizing, and cold working, are of little or no apparent value in increasing resistance to dry or wet quartz abrasion.

A Technique for Quantitative Determination of Texture of Sheet Metals. J. T. Norton. (Journal of Applied Physics, 1948, vol. 19, Dec., pp. 1176–1178). A method is described for making a pole figure of rolled sheet employing an X-ray unit equipped with a Geiger counter for measuring intensities. Small rods are cut from the sheet with their axes parallel to the plane of the sheet and making various angles with the rolling direction. With the counter tube set at the correct diffraction angle for the desired crystallographic plane each rod in turn is placed in the beam and rotated continuously about its axis. The recorder chart, synchronized with the rod rotation, plots a curve of intensity *v.* angular position R. A. R.

Physical Research To-Day—The Physical Fundamentals of Ferromagnetism. W. Gerlach. (Zeitschrift des Vereines deutscher Ingenieure, 1948, vol. 90, Dec., pp. 377–383). The following aspects of ferromagnetism are discussed: The internal causes; spontaneous magnetization and Curie temperature; spontaneous magnetization and induced magnetization; "true" magnetization; ferromagnetic alloys; spinning electrons; gyromagnetic effect; elemental moment of nickel; conditions for ferromagnetism; magnitude of the Weiss domains; energy of crystals; specific heat and magneto-calorific effect; and spontaneous magnetization and electrical resistance.—R. A. R.

Effect of Tension on the Magnetisation of Ferromagnetic Materials within the Ranges of the Para Process. K. P. Belov. (Comptes Rendus (Doklady) de l'Académie des Sciences de l'U.R.S.S., 1948, vol. 61, Aug. 11, pp. 807–809: [Abstract] Bulletin of the British Non-Ferrous Metals Research Association, 1948, Dec., p. 411). Measurements were made on nickel, 80/20 nickel–copper, 64/36 iron–nickel, 44/56 iron–platinum at temperatures up to 350° C.

The Magnetic Properties of Sintered Iron and Iron Base Alloys. W. Rostoker. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2437: Metals Technology, 1948, vol. 15, Oct.). Five alloys of the iron–silicon system and three each of the iron–nickel and iron–cobalt systems were prepared from powders, electrolytic iron 99·96% pure, carbonyl nickel 99·92% pure, and powders containing 99·87% silicon and 98% cobalt. Results are discussed of tests to determine the magnetic properties of these alloys and, in particular, to observe the effect of porosity on magnetic properties. It was found that low-porosity alloys could be produced with magnetic properties comparing favourably with those of alloys produced by orthodox methods, and alloys could be produced which would otherwise be impossible because of brittleness. The deleterious effect of nitrogen-bearing atmospheres on the magnetic properties of all the alloys except the iron–cobalt alloys is noted.—J. C. R.

The Relationship between Wetting and the Electrical Resistance between Iron and Mercury. E. Kobel. (Schweizer Archiv, 1948, vol. 14, Nov., pp. 326–330). The electrical resistance between a machined and polished iron electrode and pure distilled mercury is so great than in most cases it is two to three times greater than that of either the electrode or the mercury. This resistance can be reduced to 1% to 3% of its value if the iron is wetted with mercury. Methods for wetting, such as bombardment with mercury ions or atoms are described. The electrical resistance between iron and mercury is strongly influenced by temperature; it almost disappears when the temperature reaches 300° C. R. A. R.

Some Wetting Properties of Metal Powders. B. Kopelman and C. C. Gregg. (American Society for Metals, Oct. 1948, Preprint No. 40). Wetting characteristics of a series of metal and inorganic powders were investigated qualitatively by the examination of suspensions of the powder in the two-phase systems, kerosene–water and water/carbon-tetrachloride. Additional tests were made in which the wetting properties of the liquids were modified by additions of small amounts of hydrogen peroxide and other wetting agents in the case of the water phase, and oleic acid in the case of the oil phase. Metal powders were found to be poorly wetted by water and organic liquids, and were consequently difficult to disperse in liquid media. Results indicated that the more refractory metal powders were the most difficult to disperse. On the basis of wetting behaviour, metal powders could be classified into two groups: the lower melting metals and the refractory metals. Data indicated that the lower melting metals could be made dispersible in organic liquids by the addition of approximately 1% oleic acid. The addition of commercial surface-active agents improved the wetting behaviour of the refractory metals in water and in some cases made the lower-melting-point metals dispersible in organic liquids. Hydrogen peroxide in small amounts did not affect the wetting behaviour of metal powders.—J. C. R.

The Temperature Coefficient of the Surface Tension of Liquid Metals. A. S. Skapski. (Journal of Chemical Physics, 1948, vol. 16, Apr., pp. 386–389). From rather simple ssumptions about the symmetry of configuration of the nearest neighbours, the change in entropy connected with bringing up N-Avogadro's atoms from the bulk of the liquid metal into its free surface is estimated, and the temperature coefficient of the surface tension is calculated therefrom.—R. A. R.

The Surface Tension of Liquid Metals. A. S. Skapski. (Journal of Chemical Physics, 1948, vol. 16, Apr., pp. 389–393). The author opposes the generally accepted theory that the surface tension of liquid metals is abnormally high and that the presence of free electrons is the main cause of this. He shows that the accepted theory is due to the fact that specific surface tensions (ergs/sq. cm.) are compared, and that the influence of temperature is not accounted for. The author believes that the main cause of the surface tension of all liquids, whether metallic or not, is the same, *viz.*, the total surface energy is determined by the amount of energy required to bring the molecules or atoms (and electrons) from the bulk of the liquid to its free surface while enlarging the surface area. A short review of the recent electron theories of the surface tension of liquid metals is given.—R. A. R.

Internal Stresses in Hardened and Dimensionally Stabilised Steel. L. W. Nichols. (Engineer, 1949, vol. 187, Feb. 4, p. 132: Machinery, 1949, vol. 74, Feb. 3, pp. 140–141). **Internal Stresses in Hardened Steel Bars.** L. W. Nichols. (Engineering, 1949, vol. 167, Feb. 11, pp. 122–123). At the National Physical Laboratory hardened gauges and end standards are made dimensionally stable by holding at 150° C. for 10 hr., and cooling slowly. This paper describes an experiment with a 1-in. bar of 0·9% carbon steel, 10 in. long, oil-hardened and then stabilized, which proved that the internal stresses were not relieved by the stabilizing treatment. A 9-in. bar of high-duty cast iron had shown no change in length during nine years, but when 0·050 in. on the diameter was removed, the length increased by 0·0007 in., which was equivalent to a tensile stress of 23,000 lb./sq. in.—R. A. R.

Some Measurements of Heat Flow along Technical Materials in the Region 4° to 20° K. K. R. Wilkinson and J. Wilks. (Journal of Scientific Instruments, 1949, vol. 26, Jan., pp. 19–20). Measurements have been made of the heat flow along specimens of nickel silver, cupronickel, stainless steel, copper, and glass, one end being held at temperatures from 14° to 20° K. and the other at 4·2° K. The results are given and from them the thermal conductivities of the materials at temperatures between 10° and 20° K. are derived. R. A. R.

The Emissivity of Iron–Tungsten and Iron–Cobalt Alloys. H. W. Knop, jun. (Physical Review, 1948, vol. 74, Nov. 15, pp. 1413–1416). The spectral emissivity at $\lambda = 0{\cdot}667\mu$ was determined for an 18/82 tungsten–iron alloy and a 40/60 iron–cobalt alloy. Changes were detected at the peritectoid and peritectic reaction temperatures for the former and at the A_3 point for the latter. Emissivity changes found at 1044° K. and 1292° K. in the ferrocobalt are attributed to the order–disorder transition and the ferro- to paramagnetic transformation, respectively. The resistivity of the ferrocobalt was determined as a function of temperature.

On the Oxidation of Metals. A. Krupkowski. (Hutnické Listy, 1948, vol. 3, Dec., pp. 357–361). [In Czech]. An equation for calculation of the free energy of chemical reactions has been developed by the author from a thermodynamical law. Such free energy values have been calculated for a number of metals at various temperatures. These are given in a table. This table permits the determination of the affinity of individual metals to oxygen at various temperatures even if the metal and the oxide are both in a gaseous state, provided their vapours are in a state of saturation. Classification of metals according to the free energy of the oxidation reactions also indicates that it is easy to remove impurities from molten metals at temperatures above 1000° C. by introducing oxygen or H_2O, particularly if the oxide layer which covers the metal is in a liquid state. At normal temperatures, and at temperatures up to nearly 1000° C., a solid dense oxide layer is formed in most cases on solid and on liquid metals. The resistance of the metals to oxidation depends mainly on the density of the crystal lattice of these oxides and their resistance to diffusion; affinity for oxygen is only of secondary importance at up to 1000° C.—E. G.

The Free Energy of Reversible Reactions. A. Krupkowski. (Hutnik, 1948, vol. 15, No. 3, pp. 108–115). [In Polish]. Methods of calculating the free energy of reversible reactions in metals are explained with some examples.—W. J. W.

Examination of Materials by the "Visible Sound" Method. R. Pohlman. (Die Technik, 1948, vol. 3, Nov., pp. 465–470). Equipment has been constructed with which a visible image can be shown on a screen of defects in metal detected by ultrasonic waves. The lens for separating the interrupted waves from the transmitted waves so as to obtain a shadow image, consists of a cell containing a suspension of minute bright metal flakes (about 10μ in dia. and 1–2μ thick) in chloroform or carbontetrachloride in a flat capsule having a metal foil as one face and a rigid disc of glass as the opposite face. This cell is pressed against the metal to be examined, and is opposite to the quartz transmitter. The minute flakes in the path of the transmitted waves arrange themselves parallel to the wave front whilst those in the 'shadow' of the defect remain in random order. Using a suitable light source an image of the defect can be projected on the screen. An apparatus utilizing these principles, and having a wide range of practical application has been constructed. It consists of two columns mounted on a stand. The rear column holds the high-frequency quartz transmitter with its controls, and it can be moved and clamped in position on the stand so that objects up to 500 mm. thick can be placed between the two columns. The other column carries the receiving apparatus, projector, screen, controls, and compressed air device for pressing the lens against the metal face. The image can be focused and the adjustment of this indicates the depth of the defect from the surface. The apparatus has a range of application for detecting defects down to 0·5 sq. mm. in area and 10^{-3}–10^{-4} mm. thick.—R. A. R.

The Non-Destructive Testing of Materials. F. Rohner. (Schweizer Archiv, 1948, vol. 14, Oct., pp. 289–293). X-ray, electrical, magnetic, and ultrasonic methods of testing materials are described and their spheres of application and limits of capacity are discussed.—R. A. R.

Electronic Circuits of a Supersonic Reflectoscope. R. B. DeLano, jun. (Transactions of the American Society of Electrical Engineers, 1948, vol. 67, Part I, pp. 128–132). A supersonic reflectoscope for detecting flaws in steel is described. The important electronic feature of this device is that a short

duty cycle is employed and this permits applying alternating current direct to each valve without requiring any rectifier. R. A. R

Non-Destructive Testing of Metals by Ultrasonics. J. Piaskowski. (Hutnik, 1948, vol. 15, July–Aug., pp. 291–294). [In Polish]. Ultrasonic methods for the non-destructive testing of metals and their application are discussed.—W. J. W.

Damping Capacity of Metals. E. V. Potter. (United States Bureau of Mines, 1948, Mar., Report of Investigations No. 4194). The results of investigations on the damping capacity of many metals and alloys have been published in several journals. This Report summarizes results, describes methods of testing and their theory and accuracy, discusses the fundamental mechanisms contributing to the energy losses and their relative magnitudes, and shows the relation between damping capacity and other properties of materials. There are forty-nine references.—R. A. R.

Investigations of the Causes of the Resistance to Tempering of Steels Containing Special Carbides. W. Koch and H.-J. Wiester. (Stahl und Eisen, 1949, vol. 69, Feb. 3, pp. 80–86). Tests on carbides isolated from a vanadium steel (C 0·3%, V 2·1%) and an evaluation of similar tests on chromium steels (Cr 1% to 12%) confirm for the most part the conclusions of E. Houdremont, H. Bennek, and H. Schrader (*see* Journ. I. and S.I., 1932, No. II, p. 572). When the martensite, produced by quenching a steel containing special carbides (alloying-element carbides) from a high temperature, is tempered at temperatures too low for the formation of the special carbides, only a portion of the carbon held in solution in the martensite is precipitated as iron carbide. An increasing quantity of iron carbide is formed with increasing tempering temperature. The carbon remaining in solution limits the reduction in hardness. The presence of the carbides of the alloying elements thus increases the stability of the martensite and the root cause of this must be sought in a certain association between the carbon and the alloying element. When the tempering temperature reaches the range in which special carbides can form, the remainder of the carbon separates out as very finely divided special carbides, and the iron carbide already formed is converted into special carbides. The separation of the very finely divided carbides causes precipitation hardness which is superimposed on the reduction in hardness caused by the precipitation of iron carbide. The net result is either a further delay in the reduction of hardness, or an increase in hardness. Further increases in tempering temperature make the special carbides coalesce, thus bringing the hardness down to that of the annealed state.

Contrary to general opinion, the precipitation of the finely divided special carbides can be clearly seen in micrographs. Investigation with the electron microscope of the residues after isolation of the carbides confirms these results in the main.—R. A. R.

Ferritic Steels for Gas Turbines. G. Wood and J. R. Rait. (Iron and Coal Trades Review, 1949, vol. 158, Feb. 4, pp. 221–228; Feb. 11, pp. 281–288). After tracing the development of ferritic steels for use as gas-turbine rotor discs, the authors give details of investigations with a ferritic steel HGT3 (C 0·25%, Si 0·4%, Mn 0·4%, Cr 3·0%, Mo 0·5%, W 0·5%, V 0·75%) to determine its high-temperature characteristics. The results obtained are presented and possible future developments are discussed. Minor variations in the forging temperature could have marked adverse influences on hot strength properties, but these could be avoided by a high-temperature (1150° C.) treatment prior to hardening and tempering.—J. C. R.

Creep Tests and the Information that They Give for the Construction of Gas Turbines. W. Siegfried. (Société Française de Métallurgie, Oct. 10, 1947 : Revue de Métallurgie, Mémoires, 1948, vol. 45, Oct., pp. 361–373). The author first discusses the static long-time tests that should be made on materials for use at high temperatures in stationary and marine gas turbines (of which long lives are expected). In view of the complicated stress systems set up by the stepped-wedge method of fixing the blades to the rotors he recommends long-time tests on models of the joint in addition to creep tests on smooth and notched specimens, as well as a detailed study of the fundamental physical phenomena inherent in the strength, deformation, and rupture of the materials. The duration of the tests is very short in comparison with the expected lives, but this may be got over by studying the changes with time at raised temperatures of other properties such as the notch-toughness and magnetic properties and the microstructure. The results of creep tests on six very complex highly alloyed steels intended for use under prolonged stress at high temperatures are presented in graphs and discussed, as is also the influence of the notches of various shapes made in some of the specimens. The author considers that the curve relating the load applied in a test to the length of time required for it to produce an extension of a given amount is not a satisfactory means of determining the behaviour of a material in practical use.—A. E. C.

Comparison of the Creep Characteristics of Chromium–Nickel and Chromium–Manganese Heat-Resistant Steel of the 14/14 Type. A. M. Borzdyka. (Comptes Rendus (Doklady) de l'Académie des Sciences de l'U.R.S.S., 1948, vol. 60, Apr. 11, pp. 223–225).

Variation with Temperature of the High-Temperature Strength of Metallic Solid Solutions. A. M. Borzdyka. (Comptes Rendus (Doklady) de l'Académie des Sciences de l'U.R.S.S., 1948, vol. 60, Apr. 21, pp. 383–385 [in Russian]: [Abstract] Bulletin of the British Non-Ferrous Metals Reseach Association, 1948, Dec., p. 403). The author reports work on austenitic chromium–nickel steels, and discusses the effect of thermal history on the structure of the grain boundary and the resulting effect on the equicohesive temperature.

Causes of the Increased High-Temperature Strength of Austenitic Chromium–Nickel Steels of Large Grain Size. A. M. Borzdyka. (Comptes Rendus (Doklady) de l'Académie des Sciences de l'U.R.S.S., 1948, vol. 60, May 1, pp. 583–585). [In Russian].

Fundamentals of the Theory of Heat-Resistant Alloys. K. A. Osipov. (Comptes Rendus (Doklady) de l'Académie des Sciences de l'U.R.S.S., 1948, vol. 60, June 21, pp. 1535–1538 [in Russian]: [Abstract] Bulletin of the British Non-Ferrous Metals Research Association, 1948, Dec., p. 403). The author develops electronic theory of the heat-resistance of alloys of body-centred and face-centred cubic structure (in particular ferritic and austenitic alloys) and discusses the effect of alloying elements.

The Relation between Melting Point and High-Temperature Strength in Alloys. K. A. Osipov. (Comptes Rendus (Doklady) de l'Académie des Sciences de l'U.R.S.S., 1948, vol. 61, July 1, pp. 71–74 [in Russian]: [Abstract] Bulletin of the British Non-Ferrous Metals Research Association, 1948, Dec., p. 403). The paper reports some short-time (5–10 min.) tests at 1100° C. on Fe–Cr, Fe–Ni, Co–Ni and Mn–Ni alloys of various compositions.

The Kinetics of the Dissolution of Nitrogen in Liquid Iron and in Iron–Silicon Alloys. M. M. Karnaukhov and A. N. Morozov. (Bulletin de l'Académie des Sciences, U.R.S.S., Classe des Sciences Techniques, 1947, No. 6, pp. 735–747 [in Russian]: [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 9, p. 1982). The authors describe a method for measuring the speed of dissolution of gases in liquid metals and their degree of solubility, and give as an example its application in the case of the dissolution of nitrogen in iron and iron–silicon alloys.

The Effect of Hydrogen on the Ductility of Cast Steels. C. E. Sims, G. A. Moore and D. W. Williams. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2454 : Metals Technology, 1948, vol. 15, Oct.). Details are given of a series of tests in which specimens of solid cast steel having different hydrogen contents were subjected to simultaneous determination of the tensile properties and hydrogen analysis of closely adjacent portions. Impact tests were included in some cases. The ability of hydrogen to cause a temporary abnormal loss of ductility is confirmed; it is distinct from other mechanisms which cause permanent abnormal losses of ductility and can be completely eliminated by ageing at a moderate temperature for a sufficient time to remove all but a small residue of hydrogen. The test results are presented graphically.—J. C. R.

Steels with Higher than Normal Silicon Content. C. K. Donoho. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference, Dec. 4–6, 1947, Proceedings, vol. 5, pp. 151–179). Experiments to study the effect of silicon in steel on the porosity and mechanical properties of steel castings are described. Small tapered plates 4 × 2 × $\frac{3}{4}$–$\frac{1}{4}$ in. were cast flat in green sand. The general conclusions were : (1) Sound castings can be made

of silicon steel in green sand without aluminium ; (2) the amount of silicon required increases with the carbon content ; (3) with much more silicon than is required to give soundness there may be a reversion to pinhole porosity ; (4) with silicon-killed steels a very high pouring temperature increases the tendency to porosity ; (5) there is evidence that the melting practice affects pinhole formation ; (6) up to about 1% of silicon improves the strength with a minimum sacrifice of ductility ; (7) by an increase of silicon instead of using aluminium, cast steel of superior ductility for a given strength level is obtained ; (8) silicon steels are rather sensitive to the heat-treating temperature ; and (9) the grain-size can be controlled within limits by proper heat-treatment.—R. A. R.

Effect of Deoxidation on Mechanical Properties. M. F. Milligan. (American Institute of Mining and Metallurgical Engineers, Electric Furnace Steel Conference, Dec. 4–6, 1947, Proceedings, vol. 5, pp. 180–182). Some effects of aluminium and silicon on the properties of steel are discussed. For a given composition, a straight silicon-killed steel is less susceptible to graphitization than a silicon–aluminium killed steel, and by a proper combination of alloying elements, silicon–aluminium killed steels highly resistant to graphitization can be produced.—R. A. R.

The Effect of Ladle Additions on the Structure, Strength Properties, and Growth of Grey Cast Iron. C. W. Pfannenschmidt. (Neue Giesserei, 1949, vol. 36, Jan., pp. 1–10). After reviewing the results of Boyer's investigation of the effect of silicon-bearing additions to molten iron (*see* Journ. I. and S.I., 1939, No. I, p. 360A) the author describes his own tests in which ladle additions of calcium silicide, silicon carbide, and ferrosilicon were made. The results of numerous tensile and hardness tests are given in a table and the effects on the microstructure are shown in 32 micrographs. An addition of 0·2% of any of the above agents was sufficient to decompose any ledeburite, with a considerable improvement in the properties, and an addition of 0·4% caused all the ledeburite to disappear. This ladle inoculation also reduced the sensitivity to changes in wall thickness of the castings. R. A. R.

Mechanical Properties of Grey Cast Iron. J. Kuszewski. (Hutnik, 1948, vol. 15, May–June, pp. 227–236). [In Polish]. Five classes of grey cast iron, graded according to Polish standards, are discussed, and their mechanical properties considered.—W. J. W.

Manganese Iron. P. F. Hancock. (Foundry Trade Journal, 1949, vol. 86, Feb. 3, pp. 91–96). Details are given of the development of a new wear-resistant material called manganese iron with the composition range : Straight manganese iron : Mn 12–15%, C 3·0–3·5%, Si < 1·3%, P <0·10% ; graphitizable manganese iron : Mn 9–11%, Ni 2·8–3·2%, Si 2%, total C 3·0–3·3%, P > 0·10%. Particulars are given of the method of production in the foundry, heat-treatment, physical properties, metallography, and applications of this material. Its properties are generally similar to those of cast manganese steel, the strength and ductility being a little lower and the wear resistance somewhat higher. Possible applications include conveyor links, dredger parts, and grinding-mill components.—J. C. R.

Selection of Steels for Tool, Gauge, Fixture and Machine Use. A. L. Simmons. (Commonwealth Engineer, 1948, vol. 36, Aug. 2, pp. 9–12 : [Abstract] PERA Bulletin, 1949, vol. 2, Jan., p. 26). A description is given of a simplified scheme to assist engineers in selecting suitable steels for particular applications. The method is based on analysis of the steels rather than on makers' brands. It is claimed that fifteen steels is a minimum for most classes of work.

Special Steels for the Petroleum Industry. R. Jackson and R. J. Sarjant. (Journal of the Institute of Petroleum, 1948, vol. 34, July, pp. 445–485). The effect of composition and methods of fabrication on the behaviour of steels used in the petroleum industry is reviewed. In medium-pressure-steam corrosion in the presence of 4% H_2S, a hyperbolic relation between corrosion and chromium content is shown to exist, the presence of the liquid phase markedly increasing the corrosion. In the presence of appreciable quantities of SO_2 there appears to be a temperature (about 750° C.) at which a transition occurs in the relative influence of SO_2 on scaling ; below 750° C. the SO_2 is more active than oxygen ; above 750° C. the reverse is the case.

The effect of vanadium and molybdenum on the creep strength and the susceptibility to corrosion brittleness and weld decay of the 18/8 steels are also dealt with.—R. A. R.

Rust Proofing of Steel. (Australian Department of Munitions, Munitions Supply Laboratories, 1945, Information Circular 3 : [Abstract] Bulletin of the British Non-Ferrous Metals Research Association, 1948, Dec., p. 400). This is a survey of forty-two references in the literature, since 1939, on the methods for rust-proofing steel to be used for structural purposes ; it includes abstracts of most of the papers. Obtainable from Supt., Munitions Supply Labs., Marybyrnong, Victoria, Australia.

The Corrosion of Stainless Iron Turbine Blading. Second Interim Report. (Admiralty Corrosion Committee, Non-Ferrous Corrosion Sub-Committee, ACSIL/ADM/48/754 : [Abstract] Journal of the British Shipbuilding Research Association, 1948, vol. 3, Dec., pp. 566–567). Further laboratory and general investigations into the corrosion resistance of stainless iron are described. It appears that stainless iron will corrode in weak saline solutions, no matter what surface treatment it has received, provided that an oxygen concentration gradient is present. From an analysis of recent Service failures, it seems probable that the corrosion of stainless iron turbine blading is purely an operational function. The laboratory investigation included experiments on the effect of annealing and of the pre-treatment of stainless iron on its corrosion resistance. A study was also made of the electrode potential of stainless iron immersed in a chloride solution, as a method of assessing the relative merits of various surface treatments for the formation of a passivated film. A historical review is given of the various cleaning methods used by manufacturers, and a detailed investigation of outstanding Service failures is included.

Recent Progress in Corrosion-Resisting Nickel-Base Alloy Castings. M. M. Hallett. (Nickel Bulletin, 1948, vol. 21, Nov., pp. 154–156). **Corrosion-Resisting Casting Alloys.** M. M. Hallett. (Foundry Trade Journal, 1949, vol. 86, Jan. 13, pp. 29–31). Some applications of Corrosist "B," "C," and "D" alloys, produced by Sheepbridge Stokes Centrifugal Casting Co. Ltd., are described. Corrosist "B" and "C" are nickel–molybdenum alloys and "D" is a nickel–silicon alloy. These alloys are regarded as the equivalent of the Hastelloy alloys of America.—J. C. R.

Practical Metallurgy for the Steel Mill Engineer. W. B. McFerrin. (Iron and Steel Engineer, 1948, vol. 25, Dec., pp. 61–74). Amongst the aspects of metallurgy considered by the author are different methods of hard surfacing to improve the life of machines and equipment, and the properties and applications of high- and low-alloy steels and cast iron. J. C. R.

American Opinions on Structural Alloy Steels. R. S. Archer. (Hutnické Listy, 1948, vol. 3, Sept., pp. 261–265 ; Oct., pp. 296–301). [In Czech]. The author describes the differences between American and European practice in the manufacture and use of special low-alloy steels and emphasizes the influence and importance of the automobile industry in the United States as user of such steels. The difference is particularly apparent in the conception of hardenability, which is required to be as low as possible for a given purpose. The Jominy test, H-steels, and the work of Grossmann are also discussed and the importance of impact tests is emphasized.—E. G.

METALLOGRAPHY

The Optics and the Operation of the Photographic Microscope. The Polychromat Objective. G. A. Boutry and P. Billard. (Société Française de Métallurgie, Oct. 10, 1947 : Revue de Métallurgie, Mémoires, 1948, vol. 45, Dec., pp. 490–504). The optimum operating conditions for the photographic microscope and the design of an optical train are discussed, and tests made on a new objective are described.—A. E. C.

Microferrographic Technique. P. F. Weinrich. (Australian Institute of Metals : Australasian Engineer, 1948, Nov. 8, pp. 42–44). The technique for distinguishing between magnetic and non-magnetic phases in microsections, developed by H. S. Avery, V. O. Homerberg, and E. Cook, is described (*see* Journ. I. and S.I., 1940, No. I, p. 206A).—R. A. R.

Defects in Steel. Some Methods of Obtaining Permanent Records. H. Thompson. (Iron and Steel, 1949, vol. 22, Jan., pp. 5–7). Brief notes are given on the following methods of obtaining permanent records of defects in steel : Photographic, reflex printing, ink prints, sulphur prints and sulphur

print reproduction, oxide printing, crack prints, phosphorus printing, lead prints, nickel prints, and magneto defectograms. J. C. R.

The Preparation of Thin Steel Specimens by Cutting and the Isolation of Non-Metallic Inclusions *in Situ* by a Simplified Chemical Method. C. Benedicks and O. Tenow. (Journal of The Iron and Steel Institute, 1949, vol. 161, Mar., pp. 177–186). A method of preparing, by means of a microtome, thin steel specimens down to 20μ in thickness, is described, together with details of the development of the method. The thin specimens, so prepared, have been used for the isolation *in situ* of non-metallic inclusions in steel by means of a new chemical method. An important result of the investigations is the abundant occurrence in steel rich in aluminium nitride of thin, adsorbed films, which are visible on account of their absorption of light.

Prevention of Staining during Etching of Cracked or Porous Specimens. A. R. Edwards and K. R. Hanna. (Australian Institute of Metals: Australasian Engineer, 1948, Nov. 8, p. 37). To prevent staining of specimens with only a few cracks or a small porous area, the specimen should be etched in the normal way and immediately rinsed vigorously in warm water containing a wetting agent; it should then be washed in water and dried in alcohol. For badly cracked or very porous specimens the recommended procedure is to etch, wash, and dry in alcohol in the normal way, and then immediately cover the surface with a thin coating of clear lacquer.—R. A. R.

The Use of Non-Explosive Electrolytes for Metallographic Electropolishing. D. S. Kemsley. (Australian Institute of Metals: Australasian Engineer, 1948, Nov. 8, pp. 37–39). The danger of explosion when using solutions containing perchloric acid for electrolytic polishing is referred to and a number of non-explosive electrolytes for use on aluminium, lead, tin, iron and steel are listed. The mixture of methyl alcohol and nitric acid is recommended owing to its simple composition, rapidity of polishing, and the fact that relatively large areas can be polished. There are twenty-three references. R. A. R.

The Use of Addition Agents in Etchants for Special Effects. I. R. Lamborn. (Australian Institute of Metals: Australasian Engineer, 1948, Nov. 8, pp. 39–41). The use of addition agents in etchants to reveal temper brittleness and for general etching is discussed. In addition to cetyl trimethyl ammonium bromide, the hexyl, decyl, lauryl, and myristyl members of the same series have been investigated. They were all similar in their action, but Zephiran proved to be the most effective. It is not claimed that a positive reaction with one of the etchants is an infallible indication of temper brittleness, but relative indications after different heat-treatments can be studied and the results used as a guide to distinguish susceptible from unsusceptible steels.—R. A. R.

Electrolytic Isolation of the Carbides in Alloy and Unalloyed Steels. W. Koch. (Stahl und Eisen, 1949, vol. 69, Jan. 6, pp. 1–8). The technique for the electrolytic isolation of carbides in steel described by the author and P. Klinger in a previous paper (*see* Journ. I. and S.I., 1949, vol. 161, Jan., p. 77) is discussed and the conditions which must be observed for successful results are enumerated. It is shown by isolation experiments and examination of the carbides with the electron microscope that the carbides of ferritic-pearlitic steels can be isolated without loss by decomposition if the conditions are complied with. Isolation experiments were made on steels isothermally transformed and then tempered at below 500° C. to determine what happened to the carbon in solution when the ferrite and martensite were electrolytically decomposed. The carbon remained in the isolated residue, and that which was in solution was isolated as carbon. The technical difficulties in the isolation of the intermediate-stage and martensite-stage carbides are discussed.—R. A. R.

Progress in the Isolation of Inclusions and Structural Constituents in Alloy and Unalloyed Steels. P. Klinger and W. Koch. (Iron and Steel Institute, 1949, Translation Series, No. 374). This is an English translation of a paper which appeared in *Stahl und Eisen*, 1948, vol. 68, Sept. 9, pp. 321–333. (*See* Journ. I. and S.I., 1949, vol. 161, Jan., p. 77).

Lattice Spacing of Retained Austenite in Iron–Carbon Alloys. W. J. Wrazej. (Nature, 1949, vol. 163, Feb. 5, pp. 212–213). The author's previous assumption that the gamma solid solution in iron–carbon alloys is composed of pseudo-phases γ-G, γ-S, γ-E, makes it possible to assume the existence of retained austenite in quenched alloys below 0·6% C, the lower limit at which it had been previously recognized, and above 0·444%. Correlation of earlier data and the addition of data established by the author and a co-worker establish a linear relationship between lattice spacing and carbon content from 0·444% C to 1·776% C.—J. P. S.

Electronographic Study of the Size of Iron Crystals and of the Thickness of the Oxide Film Formed on These. P. D. Dankov and N. A. Shishakov. (Journal of Physical Chemistry. U.S.S.R., 1948, vol. 22, pp. 956–960: Chemical Abstracts, 1949, vol. 43, Jan. 10, col. 84). Iron was evaporated in a vacuum on to a celluloid film, the electron-diffraction pattern of the deposit was determined, air was allowed to oxidize the iron throughout, and the pattern of the oxide was obtained. The dimensions of the crystals were calculated by using Brill's equations. Iron crystals were 13 Å., and γ-Fe_2O_3 crystals were 17–18 Å. long. It is probable also that Fe_2O_3 films on iron are about 17 Å. (2 unit cells) thick. The results of Winkel and Haul, when corrected for a numerical error, are in agreement with this.

Generalities on Preferred-Orientation Textures. J. Hérenguel. (Société Française de Métallurgie, Feb. 18, 1948: Revue de Métallurgie, Mémoires, 1948, vol. 45, Dec., pp. 505–511). The determination of the crystalline orientation under the microscope, after etching to produce corrosion figures, is shown to be particularly suitable for analysing preferred-orientation textures. By this means the nature of the orientation community, the relative amount of metal thus orientated, and its mode of distribution in the rest of the specimen can be directly and unequivocably established. It is now known that fineness of grain is not enough to make a metal stamp well; in addition there must not be too much preferred orientation, either in quantity or in distribution. Macro-etching with corrosion figures, after electrolytic polishing, is a simple and effective means of control. The subject is illustrated by reference to aluminium.—A. E. C.

On Simple Binary Alloys Containing a Eutectic. O. Hájiček. (Hutnické Listy, 1948, vol. 3, Sept., pp. 265–269). [In Czech]. Binary alloys are studied and the author develops an equation which defines the relation between the composition of the eutectic, its melting temperature and the melting temperatures of the individual components of the binary alloy. This relation for two metals a and b is given by:

$$\frac{T_a^r - T_e^r}{T_a^r} \div \frac{T_b^r - T_e^r}{T_b^r} = b \div a$$

where T_a, T_b, T_e are the absolute melting temperature of the individual metals a and b and of the eutectic, and r is a function exponent which develops in a geometrical series with five terms $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, 4, and the value of r depends on the crystal lattices of the components of the eutectic. The values obtained with this equation are almost identical with those determined experimentally.—E. G.

Rate of Transformation of Lamellar Pearlite into Austenite in Eutectic Steels during Electrical Heating. N. M. Rodigin. (Comptes Rendus (Doklady) de l'Académie des Sciences, U.R.S.S., 1948, vol. 60, pp. 53–56: Chemical Abstracts, 1949, vol. 43, Jan. 10, col. 85). Equations are presented for the rate of transformation of eutectic steels during induction heating; these are based upon the rate of carbon diffusion, specific heat, heat of transformation of the steel, and the energy added to the system. The rate of transformation is given by the equation $dT/dx = \frac{1}{2}(\sqrt{k_2^2 + 4Vk_1} - k_2)$, where x is the linear rate of austenite formation, V is the rate of heating (heat required for the transformation being neglected) and k_1 and k_2 are constants.

Kinetics of the Transformation of Austenite into Martensite at Low Temperatures. G. V. Kurdyumov and O. P. Maksimova. (Comptes Rendus (Doklady) de l'Académie des Sciences, U.R.S.S., 1948, vol. 61, pp. 83–86: Chemical Abstracts, 1949, vol. 43, Jan. 10, cols. 86–87). The velocity of the transformation becomes measurable if the austenite is cooled rapidly, past the martensite point, to a low temperature and warmed up again. Magnetometric determinations of the rate of transformation, with an accuracy of 0·1% martensite, were made on a steel containing 6% manganese and 0·6% carbon, cooled rapidly down to −194° (in which process the austenitic structure was fully preserved), then allowed to warm up to −159°. At this temperature, the transformation

proceeded from the very beginning at a practically constant rate for some time, then continued at a very low rate; the transformation was still going on to some extent after 3 hr. when the degree of conversion was about 12%. Debyograms showed the transformation to be fairly uniform over the whole section of the sample. In stepwise cooling, the transformation was first noticed at −84° and continued at all arrests down to −170° or −180°; it was fastest at about −130° or −140° (7% transformation) in 10 min. As a rule, there exists an optimum temperature at which, in stepwise cooling or heating, the greatest amount of martensite is formed isothermally. The kinetic curves of the degree of transformation as a function of time, increase in steepness and height with the temperature falling from −84° to −133°, then decrease with further falling temperature. At temperatures above the optimum temperature, the process comes to a halt soon and at a fairly early stage of the transformation; on approaching the optimum temperature (from either side), the decay of the transformation sets in progressively later and proceeds progressively slower, *i.e.*, the initial rate is preserved longer; thus at −166°, the rate remains constant during 10 min. The summary degree of transformation, in all arrests, was about 20%. Similar curves, with a maximum of rate and of final degree of transformation at a given temperature, were found with various other manganese steels with different manganese and carbon contents. Inhibition of the austenite–martensite transformation through rapid cooling to −194°, and its renewal through stepwise warming up, were also observed on plain steel with 1·6% carbon, quenched in alkaline iced water so as to contain about 80% austenite; the summary transformation in all arrests on stepwise warming up amounted to about 10%. Transformation begins to be observable at about −100°; rates and extents of transformation are perfectly measurable at −125, −135, and −138°.

If n is the number of nuceli formed in unit time per unit volume, v = mean volume of the martensite crystals, V = volume of martensite formed in the isothermal arrest over the time t, Vo = limiting volume of martensite which can be formed at the given temperature, then $1-(V/Vo) = e^{-nvt}$. This equation is in agreement with the experimental data, at least over the first half of the transformation, *i.e.*, n is constant at a given temperature T, and proportional to the initial rate. Its log is proportional to $1/T$, whence the activation energy of formation of martensite nuclei is found = 1600 cal./mole.

Calculation of the Rate of Growth of the Ferrite Grain in the Isothermal Decomposition of Austenite. B. Ya. Lyubov. (Comptes Rendus (Doklady) de l'Académie des Sciences, U.R.S.S., 1948, vol. 60, pp. 795–797: Chemical Abstracts, 1949, vol. 43, Jan. 10, col. 86). The growth of ferrite nuclei after slow cooling to below 723° of austenite of subeutectoid composition is limited by the rate of diffusion of carbon atoms, the solubility of carbon in the new phase being substantially lower than in the initial phase. Solution of the differential equation of the concentration of carbon at the boundary of the growing grain, results in expressions for the equilibrium concentration of carbon and the radius of the grain as a function of time t, *i.e.*, the rate of growth v, with a value of the initial concentration of carbon = 0·49, its concentration in the new phase = 0·04; one has, at 720°, $v \approx 940 \times 10^{-6}/\sqrt{t}$ mm./sec. in fair agreement with experimental determinations.

X-Ray Studies on Binary Alloys of Tin with Transition Metals. O. Nial. (Scientific Faculty of the University of Stockholm, May, 1945). This report on investigations on the binary alloys of tin is in three parts; Part I on alloys with iron, nickel, chromium, and manganese; Part II on alloys with rhenium and metals of the ruthenium and platinum groups; and Part III on structural analogies.

The α-phase is a solid solution of tin in α-iron. The solubility is 4·9 atomic per cent. tin at 680° C., and 9·8 atomic per cent. at 900° C. The hexagonal β'-phase, Fe_3Sn, exists between 760° C. and 900° C., and has the lattice dimensions a = 5·447 Å and C = 4·352 Å. The β'-phase, Fe_3Sn_2, exists between 580–600° C. and 815° C. and appears to have a monoclinic structure with a = 13·50 Å, b = 5·328 Å, c = 9·18 Å, β = 103°, and eight groups of Fe_3Sn_2 in the unit cell. The γ-phase between 780° C. and 940° C. has a nickel-arsenide structure, and apparently has a small homogeneity range at about 44 atomic per cent. tin. The lattice dimensions vary from a = 4·222 Å, c = 5·198 Å, c/a = 1·231 on the iron-rich side to a = 4·225 Å, c = 5·208 Å, c/a = 1·232 on the tin-rich side. It is a curious fact that the lattice shrinks when more iron atoms are taken up. The hexagonal β-phase, FeSn appears below 745° C. and has a = 5·287 Å, and c = 4·437 Å. $FeSn_2$ is tetragonal and exists below 496° C. The unit cell has the dimensions a = 6·520 Å and c = 5·312 Å.

Iron and the intermediate phases are practically insoluble in tin. A new equilibrium diagram is set up on the basis of the results obtained.—R. A. R.

CORROSION

Galvanic Corrosion and Its Practical Significance. G. T. Colegate. (Metal Treatment and Drop Forging, 1948–49, vol. 15, Winter Issue, pp. 183–192). Galvanic corrosion, the interpretation of the normal electrode potential series, and their practical significance are discussed and the following factors determining the current that flows when two metals are coupled together are considered: The resistance of the metals and of the electrolyte, polarization, concentration polarization, and polarization caused by film formation. The precise behaviour of stainless steel in couples will depend on whether it is in the active or passive condition under the conditions of exposure; the presence of oxygen or an oxidizing agent is necessary for passivity, but the presence of either does not automatically ensure that the steel will be passive. Passivity is affected by the concentration and the temperature of a given solution, by its composition and also by the composition of the steel in question.—R. A. R.

The Texture of the γ-$Fe_2O_3.H_2O$ Crystals which Are Formed during Corrosion of Iron. N. A. Shishakov. (Journal of Physical Chemistry, U.S.S.R., 1948, vol. 22, pp. 953–955: Chemical Abstracts, 1949, vol. 43, Jan. 10, col. 101). A drop of water was placed on a celluloid film, an iron wire was immersed in the drop for several hours and the drop allowed to evaporate. An invisible film of rust remained on the celluloid. Electron-diffraction study of it showed that the flakes of γ-$Fe_2O_3.H_2O$ were parallel to the support.

Effect of Temperature and of Moisture on the Corrosion of Metals in a Sulphurous Anhydride Atmosphere. O. V. Zarubina and M. L. Turich. (Journal of Applied Chemistry, U.S.S.R., 1948, vol. 21, pp. 362–371: Chemical Abstracts, 1949, vol. 43, Jan. 10, col. 101).

The Absorption of Molecular Oxygen on Ferric Hydroxide in Water. K. Wickert and J. Kroll. (Gas und Wasserfach, 1948, vol. 89, pp. 243–245: Chemical Abstracts, 1949, vol. 43, Jan. 10, col. 81). Freshly precipitated $Fe(OH)_3$ will absorb an appreciable amount of dissolved oxygen from H_2O. Rust is believed to do the same, and this will give an increased concentration of oxygen at the iron surface under rust. Studies of the nitrogen-oxygen cell with iron electrodes indicated that the anode (nitrogen electrode) is normally attacked and the cathode (oxygen electrode) not—this is due to a passive condition of the cathode, for if the cathode surface is filed, it corrodes at a much greater rate than the anode. The rôle of local elements in facilitating corrosion is discussed, as well as the basic difference between electrolytic and chemical corrosion. In the former, electrons are transferred from the electron giver to the acceptor, in the latter they are shared.

A New Concept about the Mechanism of Passivity of Iron in Nitric Acid. R. Parshad and L. C. Verman. (Journal of Chemical Physics, 1948, vol. 16, Feb., pp. 154–155). Experiments are briefly described which support the theory that the passivity of iron in concentrated nitric acid is due to a film of hydrogen adsorbed on the iron between it and an oxygen-rich film; the latter film would stop further oxidation.—R. A. R.

The Mechanism of the Action of Inhibitors in the Course of the Dissolution of Iron in Acids. V. A. Kuznecov and Z. A. Iofa. (Journal of Physical Chemistry, U.S.S.R., 1947, vol. 21, No. 2, pp. 201–214 [in Russian]: [Abstract] Centre National de la Recherche Scientifique, Bulletin Analytique, 1948, vol. 9, No. 9, p. 1892). This is a polarographic study of the influence of different organic substances on the dissolution of iron in hydrochloric acid. The influence of anodic and cathodic phenomena was noted and an explanation sought for the delay or acceleration by reactions produced in different cases.

Environmental *p*H as a Factor in Control of Anaerobic Bacterial Corrosion. J. B. Hunter, H. F. McConomy, and R. F. Weston. (Corrosion, 1948, vol. 4, Dec., pp. 567–581). The purpose of the investigations reported was to discover the effect of alkalinity above *p*H 9·0 on sulphate-reducing bacteria which promote the corrosion of buried pipelines, and to determine whether any effect on the bacteria was permanent (' bactericidal ') or temporary (' bacteriostatic '). Cultures were prepared in nutrient solutions by incubation for 12 days at 37° C. and strong growths of sulphate-reducing bacteria were produced in a series of flasks. Predetermined amounts of KOH were added to each flask to create environments with *p*H values of 7, 8, 9, 10, and 11. After two days liquid samples were transferred to flasks containing the original nutrient media and the development of growth during incubation for further periods of 7 and 14 days was observed by exposing moist alkaline lead-acetate paper in the vapour above the solutions. This paper is darkened by the hydrogen sulphide developed by the sulphate-reducing bacteria and the amount of discoloration was thus a measure of the activity of the bacteria. The general conclusions were : (1) The activity continued at *p*H values of 7 and 8, was markedly reduced at 9, and ceased altogether at 10 and 11 ; and (2) the effect of the high *p*H values was bacteriostatic. R. A. R.

Bearing Corrosion in Turbo-Generators. J. A. Ten Broeke. (Corrosion, 1948, vol. 4, Dec., pp. 590–598). Four case histories of the corrosion of shafts of turbo-generators are cited. In one case the entire frame of the machine at the exciter end was strongly magnetized by a double earth fault in the rotor. The second was an example of wear and pitting of a wormwheel due to electrostatic charges caused by the turbine, not the alternator. The third was a case of ozone producing a deposit of oxidized oil. In the fourth example electrostatic charges were continually built up and discharged ; this was cured by fitting a brush to earth the shaft.—R. A. R.

A Practical Approach to Corrosion Resistance. W. F. Coxon. (Industrial Finishing, 1948, vol. 1, Sept., pp. 97–101). A brief description is given of equipment for testing switchgear under simulated tropical conditions. A large test room is equipped with heating, cooling, and rain-producing devices ; the switchgear to be tested is mounted inside it and it can be submitted to repeated cycles of heating, chilling, condensation, etc., at predetermined temperatures over a wide range. Results of some tests on parts coated with a petrol-resisting lacquer called " Insulus " are given.—R. A. R.

Marine Boiler Deterioration. I. G. Slater and N. L. Parr. (Institution of Mechanical Engineers, Feb., 1949, Advance Copy). A survey is made of the several forms of boiler corrosion and deterioration encountered in marine practice. Problems of design, operation, and maintenance at sea are discussed in relation to the metallurgical and electrochemical phenomena involved. As regards water-side corrosion, pitting is more frequently encountered ; general wastage, corrosion fatigue, strain-age embrittlement, and caustic embrittlement are in decreasing order of importance. Other forms of deterioration include high-temperature oxidation, bursts, high-temperature creep, and corrosion on the fire side. Several forms of each of the phenomena are illustrated and basic principles involved are discussed.

Polar-Type Rust Inhibitors. H. R. Baker and W. A. Zisman. (Industrial and Engineering Chemistry, 1948, vol. 40, Dec., pp. 2338–2347). The physical and chemical phenomena involved in the adsorption of polar solutes from non-polar or weak polar solvents are discussed and the mechanism of rust inhibition by polar compounds is analysed in terms of the properties of the adsorbed molecules. The inhibition obtainable in a petroleum oil by adding a variety of polar compounds, many of which were exceptionally pure, was observed by means of the turbine oil rusting test. The results are classified and interpreted in terms of the theory outlined and organic chemical considerations.—R. A. R.

Polar-Type Rust Inhibitors. H. R. Baker, D. T. Jones, and W. A. Zisman. (Industrial and Engineering Chemistry, 1949, vol 41, Jan., pp. 137–144). The theory outlined in a previous paper (*see* preceding abstract) is used to show that the various methods of testing the rust-inhibiting property of polar compounds in oils emphasizes the effects of different variables ; no single test will satisfy all research requirements. The turbine oil rusting test, the static water drop corrosion test, and the fog cabinet are described and recommended, and results obtained with them, using different inhibitors, are presented. The stability of rust-inhibiting fluids and their long-term storage properties are discussed.—R. A. R.

The Corrosion of Water Pipe Lines in America. H. E. Jordan. (Technique de l'Eau, 1948, Jan., pp. 15–16 : [Abstract] Revue Universelle des Mines, 1949, Series 9, vol. 5, Jan., pp. 32–33).

ANALYSIS

A Versatile Vacuum-Fusion Apparatus. M. W. Mallett. (American Society for Metals, Oct., 1948, Preprint No. 41). An illustrated description is given of a vacuum-fusion apparatus where the gas sample is extracted by a fully automatic Toepler pump and analysed in a modified Orsat apparatus. Vacuum-fusion analyses of plain carbon steels gave an accuracy of $\pm$ 0·001% for both oxygen and nitrogen. Techniques are given for the analysis of powders, non-ferrous metals, and alloys. Finally, the causes of inaccuracies in vacuum-fusion analyses are discussed with especial reference to large non-metallic inclusions and metal vapours.—J. C. R.

Spectrographic Analysis. Marguerite Héros. (Chimie Analytique, 1948, vol. 30, Dec., pp. 268–272 ; 1949, vol. 31, Jan., pp. 11–16). The principles, apparatus, methods, and applications of spectrographic analysis are described.—R. F. F.

Direct-Reading and Recording Spectrograph. P. Coheur and A. Hans. (Revue Universelle des Mines, 1949, Series 9, vol. 5, Feb., pp. 63–68). A spectrograph, which can be used for direct-reading or recorded analysis, is described. Results of tests for chromium and manganese in steels show that : (1) In the case of direct-reading analysis the average error is less than 1% and the time required is 55 sec. for the first element and 5 sec. for each additional element ; and (2) for the recorded analysis the average error varies between 1·5% and 2% and the time required is 5 min. for the first element and 20 sec. for each additional element.—R. F. F.

Calculating Boards in Quantitative Spectrochemical Analysis. C. G. Carlsson. (Metallografiska Institutet : Jernkontorets Annaler, 1948, vol. 132, No. 11, pp. 467–484). [In Swedish]. A survey is made of the principles of some different types of calculating boards, and of plate calibration by means of iron lines.—J. K.

Multiplier Photocells. J. Nicol. (British Non-Ferrous Metals Research Association : Metal Treatment and Drop Forging, 1948–49, vol. 15, Winter Issue, pp. 217–223). The B.N.F.M.R.A. received twelve multiplier photocells from the Radio Corporation of America in 1946. The cell contains ten electrodes : the photo-cathode, eight intermediate anodes or accelerating electrodes (called ' dynodes '), and a final anode. Equal potential differences of the order of 100 V. are applied between successive electrodes. An increasing succession of electrons is released from each dynode, and the cell enables current amplifications of the order of 100,000 times to be obtained. The more important features of the cells are discussed and a brief survey is given of the literature on the application of multiplier photocells, particularly to routine spectrographic analysis.—R. A. R.

An Industrial Application of Geiger-Müller Counters to the Analysis of Phosphorus in Steels. F. R. Bryan and G. A. Nahstoll. (Journal of the Optical Society of America, 1948, vol. 38, June, pp. 510–517). The phosphorus content of steels is determined by means of a Littrow quartz spectrograph equipped with Geiger-Müller photoelectron counter tubes. Emphasis is placed on operation and maintenance procedures for open hearth and foundry furnace control. Arc excitation, which is essential for sensitivity and resolution of the phosphorus line from a nearby copper line, introduces variables requiring close regulation. Temperature of the spectrograph must be maintained at nearly a constant value to prevent the shifting of spectral lines at the focal plane of the instrument. Each determination requires about one minute after the sample has been prepared and loaded, and accuracies are comparable to routine chemical results.

Modified Oxyquinolincyanide Method for the Micro-analytical Determination of Aluminium in Steel. M. Šícha. (Hutnické Listy, 1948, vol. 3, Oct., pp. 293–296). [In Czech]. A new microanalytical method for the determination of the metallic and total aluminium in steel is described. The method is based on the precipitation of aluminium with 8% $NaHCO_3$ solution. The precipitate is filtered off and dissolved, and the

aluminium is determined as aluminium oxyquinolate. The accompanying elements are either changed to complex cyanides, or separated by reprecipitation of aluminium oxyquinolate in an ammonium acetate medium.—E. G.

Thermo-Electric Method for Determining Silicon in Carbon Steel. P. D. Korzh. (Zavodskaya Laboratoriya, 1945, vol. 11, pp. 319–323 : [Abstract] Analyst, 1948, vol. 73, Oct., pp. 575–577).

Anodic and Cathodic Polarization Curves of Iron and of Copper in Sulphate Solutions with Additions of Oxidants. N. D. Tomashov, G. P. Sinel'shchikova and M. A. Vedeneeva. (Comptes Rendus (Doklady) de l'Académie des Sciences, U.R.S.S., 1948, vol. 61, pp. 669–672 : Chemical Abstracts, 1949, vol. 43, Jan. 10, cols. 47–48).

A New Procedure for the Determination of Oxygen in Powders of Soft Iron, Steel and Some Other Metals. G. Naeser. (Stahl und Eisen, 1949, vol. 69, Jan. 6, pp. 19–22). A description is given of an apparatus and procedure for rapidly determining the oxygen in small samples of metal powders such as are used for powder metallurgy. The sample is mixed with carbon and heated in a closed electric furnace containing pure nitrogen to a temperature of 1300° C. The volume of carbon monoxide formed is read directly on burettes connected to the furnace chamber. The method takes 10–20 min. for iron and is sufficiently accurate to be used for controlling the quality of the powder.—R. A. R.

Determination of Iron in Lorraine Iron Ores. J. Baron. (Chimie Analytique, 1949, vol. 31, Feb., pp. 29–30). The author discusses the difficulty of bringing into solution the whole of the iron contained in the ore sample. He describes two methods of preparing the solution for analysis. The first method, in which the ore, after calcination at 550° C., is attacked by HCl, is suitable for all routine determinations, the results obtained varying by 0·05% to 1% from the actual amount of iron present. The second method, more complex, must be used when strict accuracy is required. After calcination and attack by HCl, the solution is evaporated to dryness. The mass is dissolved in 20 c.c. HCl and 100 c.c. boiling water, and filtered. The residue contains silica with iron and alumina. This siliceous residue is treated with alkaline carbonates in a platinum crucible and after melting at a red heat for a few minutes, the mass is placed in water, attacked by HCl, and dried. After redissolving with boiling water and HCl the solution is filtered and the residue contains the iron and alumina. After adding bromine water and NH_4Cl to the residue, the iron and alumina are precipitated by NH_4OH. The precipitate is dissolved by HCl and the solution added to the first filtrate. When drying both residues the temperature must not exceed 125° C.—R. F. F.

Two Modern Methods for the Determination of Vanadium in Ferrovanadium. B. E. Jaboulay. (Chimie Analytique, 1949, vol. 31, Jan., p. 10). In the first method V_2O_5 is reduced to V_2O_4 using a slight excess of ferrous sulphate. This excess is destroyed by ammonium persulphate and titration with permanganate reverts the V_2O_4 to V_2O_5. In the second method, a slight excess of permanganate is used to oxidize vanadium to V_2O_5. This excess is neutralized by barium diphenylamine sulphonate which acts as indicator during titration with ferrous sulphate. The change from violet to green occurs as soon as the V_2O_5 is completely reduced to V_2O_4. Care must be taken to maintain the correct acidity.—R. F. F.

ECONOMICS AND STATISTICS

Progress in the Metallurgical Industries in Other Countries. A Visit to the Steel Industry of Great Britain. J. Souvairan. (Métallurgie, 1949, vol. 81, Feb., pp. 5, 7).

The Italian Metallurgical Industry. (Métallurgie, 1949, vol. 81, Feb., pp. 7–8).

The Canadian Steel Industry. C. More. (Métallurgie, 1949, vol. 81, Feb., p. 8).

The Steel Position in the United States. (Métallurgie, 1949, vol. 81, Feb., p. 8).

The Hungarian Iron and Steel Industry. (British Iron and Steel Federation Monthly Statistical Bulletin, 1948, vol. 23, Dec., pp. 11–18). The present economic position and the outlook of the Hungarian iron and steel industry are surveyed. There are three steelmaking concerns, Rimamurány, Manfred Weiss, and the State Steel Works ; their combined production in 1947 was 305,000 tons of pig iron and 590,000 tons of steel ingots.—R. A. R.

The Task and the Development of the Polish Metallurgical Processing Industry. W. Remin. (Hutnik, 1948, vol. 15, Apr., pp. 170–173). [In Polish]. The developments planned for the Polish metallurgical industry up to 1955 are discussed.

Coal Production in Poland in 1949 and Distribution of the Output. (Glos Ludu : Bányászati és Kohászati Lapok, 1948, vol. 3, Dec. 15, p. 331). [In Hungarian]. It is planned to produce about 75 million tons of coal in Poland in 1949, and it is intended to allocate this as follows (data in millions of tons) : Export 26, industry 24, domestic purposes 10·6, coking and briquetting 7·6, transport 7·6. It is also intended to export 1,430,000 tons of coke in 1949.—E. G.

BOOK NOTICES

AMERICAN SOCIETY FOR TESTING MATERIALS. "*A.S.T.M. Specifications for Steel Piping Materials.*" Prepared by A.S.T.M. Committee A-1 on Steel. 8vo, pp. viii + 319. Philadelphia, 1948 : The Society. (Price $3).

This compilation of standards on steel piping materials is the sixth edition. The book contains fifty standards, grouped according to the following classes of materials : Pipe, boiler superheater and miscellaneous tubes, still tubes, castings, forgings and welding fittings, bolting, and grain size. Each standard and tentative specification is given in its latest approved form.—R. E.

DAEVES, K. and A. RECKEL. "*Grosszahl-Forschung und Häufigkeits-Analyse. Ein Leitfaden.*" 8vo, pp. 66. Verlag Chemie, G.m.b.H., Bergstrasse, Weinheim, 1948. (Price : 3.20 M.).

This interesting publication is a welcome addition to the literature dealing with the practical application of statistical methods to research and to quality control problems. From the point of view of English speaking technicians, it is, however, unfortunate that the authors have adopted a literary style which will only be intelligible to those possessing a thorough knowledge of the German language, and a reasonably adequate knowledge of statistical methods.

The authors say that the construction of 'control charts' is based on the erroneous assumption that the frequency distribution of the population is a simple and symmetrical normal Gaussian distribution ; the frequency distribution does basically follow the Gauss law, but the total population often consists of a mixture of two or more different but normally distributed populations.

Particulars are given of a simple graphical method of testing frequency diagrams for normality, and it is shown how many frequency diagrams may be split up into two or more normal diagrams.

Briefly, the method described depends upon the type of curve obtained when cumulative frequency expressed as a percentage of total population, *i.e.*, the ogive, is plotted against the variable on arithmetic probability paper. If the frequency distribution is normal one obtains a straight line. (It is pointed out that there are cases in which a straight line is only obtained when logarithmic probability paper is used). The characteristics of frequency diagrams given by a simple mixture of two or more normal populations having different modes are then described, and the authors show how such 'mixed' frequency diagrams can be dissected into their component parts. Next, the case when the two mixtures have the same, or very nearly the same, mode but a different range is considered. Another interesting section shows how probability paper may be used to expedite the extrapolation of incomplete distributions.

Finally, the authors describe a number of practical applications of frequency-diagram analysis to technical and scientific problems.—J. FERDINAND KAYSER.

INSTITUTE OF FUEL. "*Waste-Heat Recovery from Industrial Furnaces.*" 8vo, pp. ix + 384. Illustrated. London, 1948 : Chapman and Hall, Ltd. (Price 35*s.*).

This volume is based on a series of papers presented to the Institute of Fuel at a Conference on Industrial Waste Heat Recovery. According to Sir Frank Smith in his foreword, "It can be presented for serious study without reserve to all who are interested in the conservation

of fuel." The papers, abstracts of which have already appeared in the Abstract Section of this *Journal* are as follows: Introduction, by G. N. Critchley; Total, Recoverable, and Returnable Heat in Combustion Gases, by P. O. Rosin; Some Simplified Heat Transfer Data, by Margaret Fishenden and O. A. Saunders; An Experimental Determination of the Factors Governing the Design of Regenerators with Special Reference to Coke Ovens, by T. C. Finlayson and A. Taylor; Tubular Metallic Recuperators, by G. N. Critchley and H. R. Fehling; Waste-Heat Boilers, by W. Gregson; The Utilisation of Waste Heat in the Carbonising Industries, by J. G. King and F. J. Dent; Waste-Heat Recovery in the Metallurgical Industry, by J. A. Kilby, W. G. Cameron, E. C. Evans, A. H. Leckie, J. L. Harvey, and A. E. Balfour; Waste Heat Recovery in the Glass-Container Industry, by W. A. Moorshead; and, Heat Transfer Data, by Margaret Fishenden and O. A. Saunders.—R. E.

JONES, J. H. "*The Steel Industry and Nationalisation*," 8vo, pp. 32. London, 1948: Sir Isaac Pitman and Sons, Ltd. (Price 1*s*.).

The author of this small work has been closely associated with the British iron and steel industries for many years, and from 1919 to 1946 was Professor of Economics and head of the Economics Department at Leeds University. The views expressed in the pamphlet are therefore based upon research and the outcome of a lifelong interest in the economic problems of the industry.—R. E.

MCKEOWN, J. "*The Properties of Soft Solders and Soldered Joints*." With a Foreword by H. Moore. 8vo, pp. 140. Illustrated. London, 1948: British Non-Ferrous Metals Research Association. (Price 17*s*. 6*d*.).

The British Non-Ferrous Metals Research Association has from its first days taken an interest in the problems of solders and soldering. The results of its first investigations appeared in 1932 in the Association's Research Monograph No. 1, "*Tin Solders*," by S. J. Nightingale, a second edition of which, revised by O. F. Hudson, appeared in 1942. Meanwhile, the tin shortage following the beginning of the war in 1939 stimulated the B.N.F.M.R.A. to researches on solders of lower tin content.

Information was lacking on the mechanical properties of the 'tin-economy' solders and joints made in them. To fill this gap a wide variety of tests was carried out over a series of temperatures, including tests on the creep properties of joints made with a range of solders. In addition, comparison was made (by soldering, area-of-spread, and capillary penetration tests) of high-tin and 'tin-economy' solders. The hot tearing of solders was examined in order to define suitable compositions for the avoidance of this trouble; and investigation was made of the soldering of aircraft oil-coolers by lead-rich solders.

This experimental work and the conclusions drawn from it are described in the present volume by Dr. John McKeown (head of the Association's Mechanical Testing Section) who led the team concerned with this war-time research.

RIDDIHOUGH, M. "*Hardfacing by Welding*." 8vo, pp. 127. Illustrated. London, 1949: The Louis Cassier Co., Ltd. (Price 8*s*. 6*d*.).

The author of this book, the first devoted solely to the subject, is a recognized authority on hard-facing. The book enables the welding and maintenance engineer to tackle efficiently the job of hard-facing every type of metal. It is intended as a practical manual covering every stage of the process—design of component, choice of hard-facing alloy and technique of depositing, and inspection and finishing methods. It contains the following chapters: Hardfacing Rods and their Development; Designing the Deposit; Designing for Specific Jobs; Characteristics of the Metals Commonly Used for Blanks; Preheating and Cooling; Heat Treatment for Hardfacing Various Types of Metals; Equipment and Jigs for Hardfacing; Hardfacing Techniques; Inspecting, Machining and Grinding the Deposit; and, Estimating and Planning. In an Appendix a list is given of the British and American hardfacing welding rods, including trade names, manufacturers, and approximate composition.—R. E.

NEW PUBLICATIONS

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS. "*Proceedings of the Thirty-first Conference, National Open Hearth Committee of the Iron and Steel Division, Pittsburgh, Pa., Apr.* 12–14, 1948." Vol. 31. 8vo, pp. 340. Illustrated. New York, 1948: The Institute.

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